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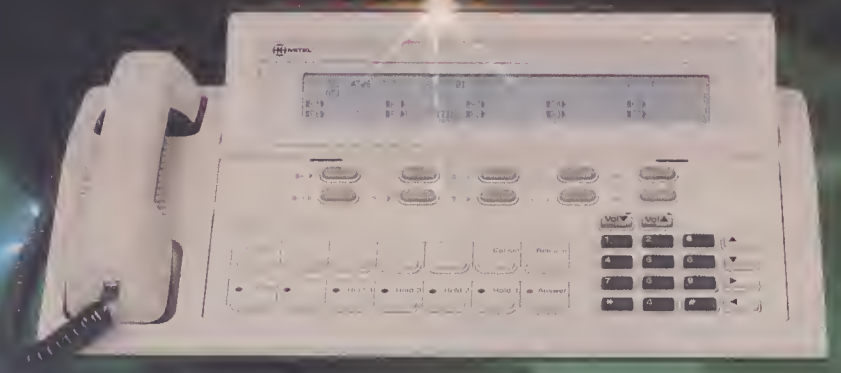
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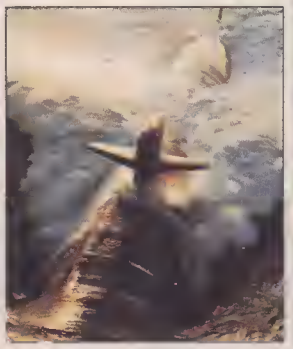
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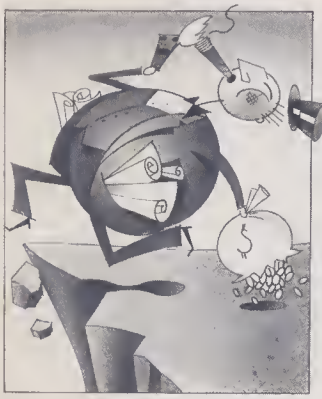
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Cover Photo by Larry Williams

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TERRY ALLEN

The U.S. is heading toward second-rate economic status

If the United States continues on its present course, it will probably lose its status as the world's leading economic power before the end of this century.

A number of factors lead to this conclusion. Although the U.S. has more capital for investment than any other nation, too much of it is being used to buy up undervalued assets rather than to fund new ventures that promise future growth. Corporate raiders and large conglomerates find it easier, and less risky, to assemble packages of hundreds of millions—even billions—of dollars to buy up existing companies. This get-rich-quick scheme is almost never an improvement for the nation; jobs are lost, plants close, manufacturing goes offshore, and corporations are stripped of assets that are sold to the highest bidder. A few individuals are becoming incredibly rich this way, even when they fail in their efforts, because the management of a targeted company will often mortgage the enterprise to pay off a raider.

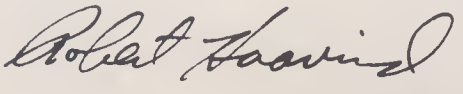
The high cost of capital encourages such short-term, speculative goals. Capital invested for a quick return generally will not be aimed at technological innovation. Meanwhile, the creative ideas that continue to flow from American laboratories often are not used to build or expand industries in the U.S. but instead are licensed to foreign corporations that can manufacture the products resulting from new technology more cheaply than they can be made here. Although venture capital is more available in the U.S. than it once was, investors are turning away from technology toward sectors where the risks appear lower and the returns quicker, such as fast food. Therefore companies developing innovative products frequently go out of business, or else find a new way to finance their high-risk ventures: selling out to foreign companies.

Recently several of our editors visited a variety of technology firms in Japan. Almost all of them are expanding or building new plants and are investing heavily in new capital equipment to make advanced products. They are boosting research efforts and moving into new technologies. Some are stepping up the ladder to higher-value-added products. (A Special Report on trends in Japanese technology will appear in the August issue.)

At the same time, many companies in Silicon Valley and along Route 128 are laying off workers, cutting back expansion plans, and canceling capital equipment orders.

One technology sector that is surging forward is the defense industry, supported by funds that add to the swollen federal deficit (a major cause of the overvalued dollar and the high cost of capital). The weapons being built at huge expense can't protect the U.S. from becoming a second-rate economic power.

Building fences around the country won't help, either. The U.S. will regain its technological and economic momentum only when American management and the investors who control the flow of capital see the value of nurturing the innovative technologies that can build tomorrow's industries.



Robert Haavind

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Martin E. Thompson
Corvallis, Ore.

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Rigid, unthinking adherence to established institutions and relationships perpetuates irrationality and closed-mindedness. That new discoveries can, and do, arise out of such conditions seems very fortunate. I

MATT BROWN/ WEST STOCK

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Lee Johnson, Technical Director
Protan Laboratories
Redmond, Wash.

Small documents for small businesses

In "Micrographics shrinks document storage costs" (April 1985, p. 64), you imply that one must have a large volume requirement

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LETTERS

A balanced assessment

I very much enjoyed Dwight Davis's balanced presentation on the Strategic Computing Initiative. ("Assessing the Strategic Computing Initiative," April 1985, p. 41). I was particularly happy to see J. C. R. Licklider receive some of the recognition he so greatly deserves. Not only is he a brilliant computer scientist, but his influence at DARPA in shaping modern computer technology can be compared only to that of a great editor in a publishing house.

I have one small criticism: You fail to give recognition to another in the series of excellent DARPA office directors—Clinton Kelly, who is the director of the Engineering Applications Office. My husband, Craig Fields, is the deputy director of that office, not the director as was stated.

Alison Fields
Washington, D.C.

You did an excellent job of presenting a thoughtful view of a topic that does not yield to easy generalities of "good guys" and "bad guys." Your presentation seemed balanced, and your quotes from me accurately expressed the essence of my concerns. Congratulations on a good job of research and writing.

Terry Winograd
Associate Professor
Stanford University
Stanford, Cal.

Congratulations on your article about the Strategic Computing Initiative. You did an excellent job of providing an accurate and fair picture of the situation. In fact, it is the most careful and thorough job I've seen so far, and I am pleased to have it in the public press. It is also well written and interesting, and we will certainly suggest it to people as a reference.

Severo M. Ornstein, Chairman
Computer Professionals for
Social Responsibility
Palo Alto, Cal.

Your article on the Strategic Computing Initiative is accurate, up to the minute, and reflects an open attitude. But it left me feeling somewhat hopeless about the entrenched nature of the relationship between government and industry. Whether DARPA "steps in where others fear to tread" is as much a question now as it was with DARPA's first project. DARPA's track record does not predict its future success or failure, nor does it justify the content of the SCI program and the comfortable dependency of the industrial sector on it.

Rigid, unthinking adherence to established institutions and relationships perpetuates irrationality and closed-mindedness. That new discoveries can, and do, arise out of such conditions seems very fortunate. I can envision, however, a much more dynamic and prosperous way of fostering such creativity.

Anne Beaumont
Computer Professionals for
Social Responsibility
Santa Cruz, Cal.



MATT BROWN/WEST STOCK

New uses for chitosan

We enjoyed your comprehensive article "Biotechnology goes to sea" (Feb. 1985, p. 34), particularly your mention of "chitin" and "chitosan," chemicals derived from crab and shrimp shells.

Our company, Protan Laboratories, is one of the world's major producers of chitosan. We think, naturally, you should have reported more fully on chitin since it appears that, after fish and perhaps seaweed alginates, chitin may be the most important material derived from sea organisms.

Chitosan—which is the deacetylated form of chitin—is now used primarily as a polyelectrolyte for treatment of high-organic wastewaters, particularly to produce sludges that can be dried and used as animal feeds. Although this is the only application now sanctioned by the FDA, we are applying for FDA approval for use of chitosan in clarifying fruit juices and wines—a common application in countries where sufficient supplies are available.

Chitosan is also being increasingly used as a film former, blood coagulator, and enzyme carrier. It may provide a highly efficient fungicide for both plants and humans. And it appears to be quite effective in facilitating wound healing and treating burns.

Lee Johnson, Technical Director
Protan Laboratories
Redmond, Wash.

Small documents for small businesses

In "Micrographics shrinks document storage costs" (April 1985, p. 64), you imply that one must have a large volume requirement or substantial capital to be able to afford computer-assisted microfilm retrieval. This is somewhat misleading, in that systems as sophisticated as the KAR 4400—which you describe as "typical"—are available from Bell and Howell for roughly half the $76,000 price you quote. Its system is also minicomputer-based and is equipped with the necessary cameras, reader/printers and display terminals, as well as all software.

In a recent study, our company found a great need for and interest in the combined benefits of microfilm and computer access by companies that are outgrowing manual, paper-filing systems, or even earlier microfilm systems. According to our research, the market for microfilm and for microfilm-based CAR systems will be around for many years, due to the unproven economics of optical disc–based systems. Furthermore, these disc systems are likely to be used at only the most sophisticated organizations.

Allan S. Price, President
Price Marketing Group
Chicago, Ill.

Realistic energy planning

"Nukes II" (March 1985, p. 37) was well written and interesting. In the past, energy planners have tended to exclude uncertainty calculations from their planning, thus giving the appearance of certainty. This is one reason the industry is in its present state. Realistic energy planning, however, projects into an uncertain future and tries to minimize risks.

One example of such planning is provided by the Northwest Power Planning Council, which was formed by Idaho, Montana, Oregon, and Washington, when faced with the consequences of the Washington Public Power Supply System (WPPSS) defaulting. The council attempts to work into a 20-year planning future by developing scenarios for electric energy demand growth and analyzing resource options—ranging from conservation and hydrogeneration to thermal plants, including gas turbines, coal-fired, and nuclear—to meet the projected demand scenarios.

The effect of this process is to identify and acquire lowest-cost resources first. The council's activities may also focus attention on new energy resources that should be researched for possible future need. Interestingly, results of the council's studies show that conservation and a modest amount of hydrogeneration will meet the region's projected energy needs for the next 20 years.

Martin E. Thompson
Corvallis, Ore.

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UPDATE

New software creates instant IC compilers

A group of former Bell Labs researchers have taken silicon compilation—the automatic generation of integrated circuit layouts (HIGH TECHNOLOGY, June 1985, p. 18)—an important step further. Called Generator Development Tools (GDT), the new software captures the expertise of skilled IC designers as they work, so they can author their own silicon compilers automatically.

GDT, offered by Silicon Design Labs (SDL—Liberty Corner, N.J.), translates the designer's procedure into a new circuit description language called L, which allows subsequent designs to be compiled by a simple "fill-in-the-form" technique. In effect, a compiler is generated using the designer's particular style and knowledge.

"The language and tools of GDT are entirely technology-independent," says Hal Alles, SDL's vice-president of engineering, "so they can be used to build silicon compilers for any mask-defined technology: CMOS, NMOS, bipolar—even analog circuits." Written in the C language and operating under Unix, GDT costs $75,000 per workstation and is available now for Sun workstations. The tools will soon be adapted for other workstations, such as the Apollo Domain.

If GDT proves to have the generality its authors claim, it could become the Lotus 1-2-3 of the semiconductor industry; it could provide a wide range of automated tools for the design of systems, custom ICs, and printed circuit boards. Indeed, during 1985/86 SDL plans to release several other software products based on GDT, some targeted to system designers rather than IC designers.



Matsushita's 4-inch-thick panel uses 3000 scanning electron beams.

Flat TV tube challenges liquid crystal displays

Most flat-panel display media, such as liquid crystals, fail to match the familiar cathode-ray tube's bright color, ease of viewing, and ability to depict moving pictures without blur. One solution: retain the basic CRT technology—using an electron beam to paint images on a phosphor-coated screen—in a flattened package. Now Matsushita has made significant progress toward that goal.

An ordinary CRT must be deep in order to leverage a small deflection of the electron beam into a screen-width scan. Matsushita's new display avoids this requirement by producing 3000 separate electron beams, each simultaneously scanning its own portion of the screen. As a result, the company's 8 × 11–inch prototype panel is only 4 inches thick.

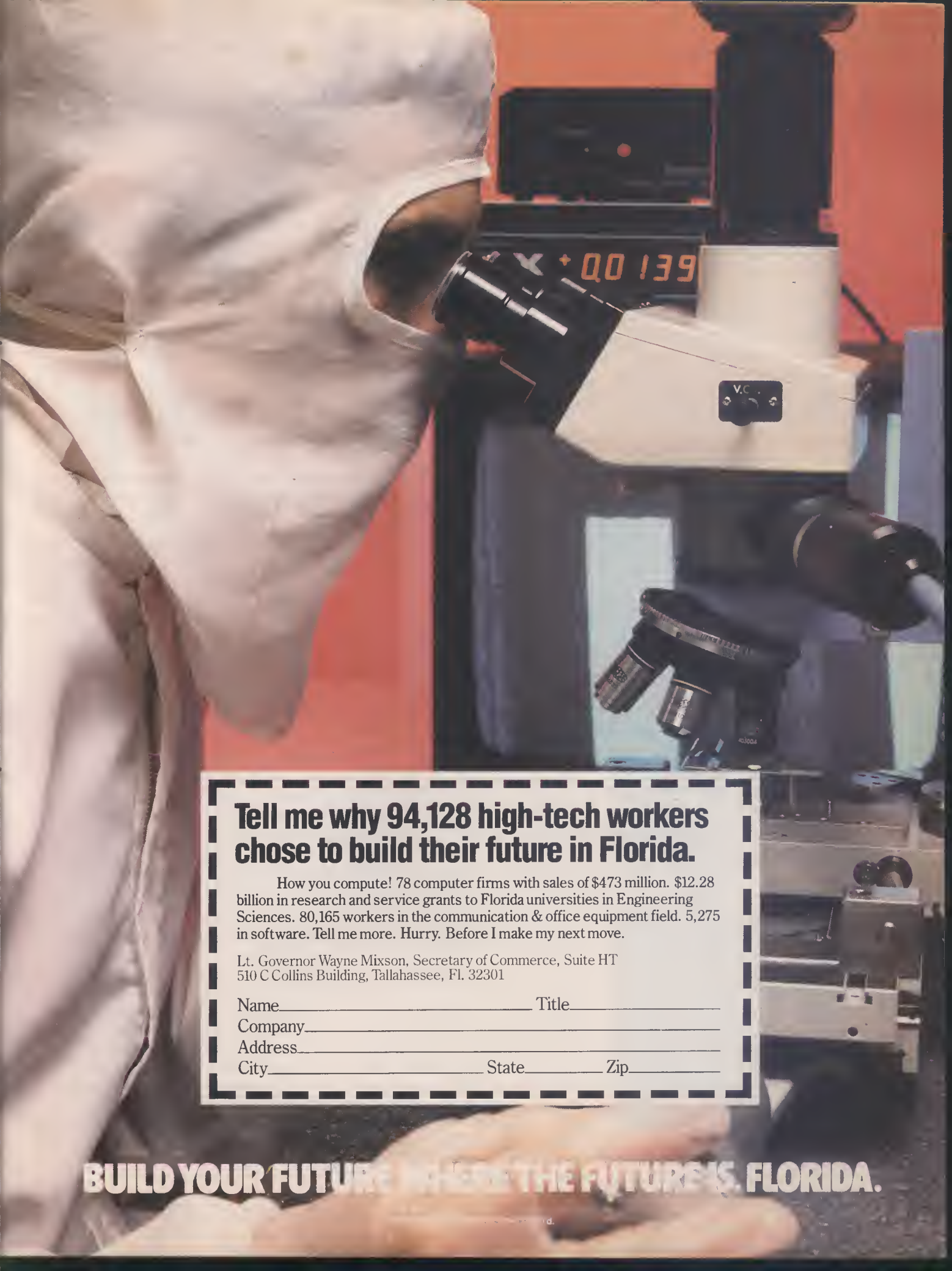
Another advantage of Matsushita's design is lower voltage: It uses only 10 kilovolts versus 24–30 kV in a standard tube. That's because multiple beams cause more electrons to hit the phosphor in a given time period than a single beam does; with more electrons less energy is needed to achieve the same picture brightness. The lower voltage reduces bulk, simplifies manufacture, and increases reliability, says Judson Hofmann, vice-president of the Matsushita Technology Center's video division (Secaucus, N.J.). The tube has been shown only in Japan; marketing plans for the U.S. have not been announced.

A speedy reading on catalyst efficiency

A program to help small companies quickly assess the chemical and economic value of new catalysts (substances that speed up chemical reactions) is being launched at the University of California's Lawrence Berkeley Laboratory (LBL). The program identifies not only the products generated by the catalyzed reactions but also their quantities and how long the catalysts will function before they must be replaced—a key consideration in view of the high cost of most catalysts. In many companies, these data are now obtained by trial and error or lengthy experimentation.

In a typical assessment, a small amount of the catalyst (5–50 grams, depending on the reaction) is placed in a reactor with specified liquid or gaseous reactants. The reaction—conditions for which are set by the customer—then proceeds. Small amounts of the reaction products are diverted into a gas chromatograph for analysis; most of the products are saved for more detailed study.

The estimated cost of the analysis to non-LBL users will be about $1000 a day, according to chemist Heinz Heinemann of the materials and molecular research division. Many chemical and petroleum process developers will find that price a bargain, however. Although private companies often use proprietary systems similar to the LBL unit, their $200,000-plus price tag usually limits them to the large, well-financed laboratory.



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UPDATE

October dubbed High Tech Month

Based on the success of National High Technology Week last October, Congress has passed a joint resolution designating October 1985 as National High Technology Month. The bill was sponsored by Congressmen Mervyn Dymally (D-Cal.) and Manuel Lujan, Jr. (R-N.M.).

Inspired by an article in HIGH TECHNOLOGY in October 1983, this national program is intended to better inform the public, and particularly America's youth, about emerging technologies. Activities during the month will also focus on the managers and professionals behind innovations that are creating new businesses and industries. Last year, many states as well as individual organizations sponsored programs tied to High Technology Week. For example, the first computer fair for children—Bits and Bytes—was held in California. North Carolina governor James B. Hunt directed all 142 school districts in the state to hold special science/technology events. Minnesota initiated a student essay contest about the world of the future, and the University of Alaska beamed a seminar on technology to 72 stations in Alaska and California.

Those interested in organizing activities for this year can obtain a list of ideas from Georgianna Anderson-Land, Executive Director, Congressional Caucus for Science and Technology, H2-226 House Annex #2, Washington, DC 20515, (202) 226–7788.



Minnesota's Governor Rudy Perpich honors 12th grader Loren Eyres for his prize-winning essay on developing an artificial eye.

Voice and data share the line

Home and small business computer users will soon be able to speak on the telephone while their computers are on the line, thanks to a device now being patented by California's Pacific Bell. Known as Victoria, the device is a multiplexer that can digitally encode two voice conversations, as well as carry one high-speed data stream that would provide access to database services and four low-speed streams that could be used for utilities monitoring—all on the same pair of copper wires. The device separates the seven data streams into individual time slots, creating a single digital bit stream that avoids the cross talk that can occur with analog transmissions.

Victoria will be field tested in northern California later this year. If the tests are successful, Pacific Bell plans to install the product throughout its territory in 1986, and hopes to persuade other phone companies across the U.S. to follow suit, says Michael Bandler, the company's VP for network engineering and planning.

Automated microscope speeds up biopsy analysis

A digital image processor that analyzes biopsy specimens quantitatively in a relatively short time has been developed by the German Cancer Research Center (Heidelberg, West Germany). The system is designed to replace the current method of diagnosing cancer in a biopsy specimen: A pathologist examines thin sections of the tissue under the microscope and characterizes them as cancerous or normal on the basis of subjective qualities such as cell shape, size, and color.

The new system, a prototype of which was exhibited recently at the Hannover Fair, employs more objective criteria for describing and comparing tissue specimens. A computer moves a microscope stage automatically, scanning across the tissue section at low magnification in many small steps, so that every part of the specimen fills the microscope field. Each image is converted into a video signal, which is then processed by a digital image analyzer in about a second; the results are stored in memory.

The image analyzer, consisting of multiple MC68000 microprocessors in a highly parallel configuration, distinguishes tumor tissue from normal tissue according to the number of cells and the optical density of the cell nuclei. Both parameters are greater in tumors than in normal tissue. When the entire section has been scanned, the computer displays a matrix that indicates symbolically which parts of the specimen are cancerous. This analysis would take a technician about two hours to perform. The computer does it in 15 minutes.

SCIENCE/SCOPE

A new radar can map military targets with high resolution equal to that of infrared devices, even in rain and other bad weather. The Advanced Synthetic Aperture Radar System (ASARS-2), designed to complement electro-optic sensors, is flown on a U.S. Air Force TR-1 reconnaissance aircraft and provides real-time radar imagery to a ground station. ASARS-2 operates in all weather at ranges far exceeding the capabilities of infrared and other electro-optic devices, thanks to new state-of-the-art signal processing and other advances. The Air Force gave the system an excellent rating after it underwent strict operational performance tests as part of a "fly-before-buy" program. Hughes Aircraft Company is producing the system under a development and production contract. Eventually ASARS-2 is expected to be adapted for tactical aircraft and mobile tactical stations.

Jam-resistant communications have been introduced into NATO by a new terminal for AWACS early-warning aircraft. The Joint Tactical Information Distribution System (JTIDS) Class 1 terminal is designed to combat the formidable and growing electronic countermeasures threat to tactical communications. JTIDS uses principles of time division multiple access to provide secure, high-capacity communications for AWACS radar planes and ground stations. The system relays a wide variety of information, such as command and control, surveillance, intelligence, force status, target assignments, warnings and alerts, weather, and logistics. Software filtering lets each participant select data pertinent to his own needs. Hughes is producing the JTIDS terminal for use with NATO's Airborne Early Warning/Ground Environment Integration Segment (AEGIS).

Lasers soon will be inspecting solder joints of fighter aircraft radars, thanks to new manufacturing technology being set in place at Hughes. Solder joints will be examined by a computerized technique using lasers and fiber optics, the glass threads that carry laser light transmissions. The process will free manufacturing personnel from tedious and time-consuming inspections of more than 36 million solder joints created in a single year's production. The project is part of an Industrial Modernization Incentive Program (IMIP) awarded by the U.S. Navy and Air Force. IMIP is a share-the-savings concept that will reduce costs of the F-14, F-15, and F/A-18 radar programs by more than $10 million, while improving the quality and reliability of the systems.

Two high-power direct-broadcast satellites will carry family-oriented and religious programming for Dominion Video Satellite, Inc. The Hughes satellites will incorporate a novel design, combining existing technologies of spin-stabilized satellites and body-stabilized satellites. Each will carry large, winglike solar arrays similar to those on body-stabilized satellites. The wings will extend 110 feet, generating 5,000 watts of electrical power for eight channels of communications. A central spinning section will provide gyroscopic stability and additional electrical power for basic housekeeping functions. The satellites will be equipped with batteries to provide full power when the spacecraft pass through Earth's shadow and the sun is blocked from the solar cells.

Hughes' Santa Barbara Research Center is seeking experienced engineers and scientists to further develop advanced IR focal plane technologies. We need custom integrated circuit designers, nuclear effects engineers, material scientists, semiconductor device scientists and process engineers, and IR system analysts. To learn how to become involved in this innovative technology, contact the Santa Barbara Research Center, Professional Employment, Dept. S2, 75 Coromar Drive, Goleta, CA 93117. Equal opportunity employer. U.S. citizenship required.

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Meeting global competition

by John A. Young
President and Chief Executive Officer, Hewlett-Packard

This nation's ability to compete has seriously declined over the past 20 years both in our domestic markets and abroad. I had long suspected this trend, but as chairman of the President's Commission on Industrial Competitiveness from 1983 to the present, I've had a sustained opportunity to study it in alarming detail. Consider the following:

- In productivity growth, we've been surpassed by all our major trading partners. The Japanese rate, for example, is five times our own.
- Real hourly wages in the business sector were virtually stagnant from 1973 to 1980, and since then they've actually declined.
- Our manufacturing sector isn't generating the kinds of returns on assets that encourage investment. Twenty years ago the average real pretax return on manufacturing assets was almost 12%. In 1983, it was about 4%.
- U.S. trade deficits are at an all-time high—a total of more than $125 billion last year. From the turn of the century until 1971, we ran a positive balance of trade. Since then there's been a steady and alarming trend to the negative.
- Since 1965, seven out of ten U.S. high technology industries have lost world market share. Last year this country had a larger trade deficit with Japan in electronics—$15 billion—than in passenger cars.

What can we do to reverse the competitive erosion of the past two decades? It would be nice if the commission could simply say, "Do such and such, and everything will improve." Unfortunately, there is no panacea; our ability to compete depends on many factors, all interrelated. Nevertheless, the commission was able to group those factors into four subject areas—technology, capital, human resources, and international trade—and to come up with key findings and recommendations in each of them that should serve as the basis for a concerted national program.

Creating technology. Technology is our greatest asset in world competition, but there should be cause for concern about the kinds of technologies we investigate: The U.S. spends a smaller percentage of GNP on civilian R&D than either West Germany or Japan. In other words, we invest proportionally less than our major trading partners in those basic areas of inquiry that could lead to commercial competitive advantage.

In the years immediately after World War II, government R&D was a great catalyst to industrial applications. But while roughly half of all the R&D performed in this country is still funded by the federal government, most of that spending goes for defense and space research. In the commission's view, any spillover of these R&D efforts to commercial applications is incidental at best.

That is why we called for the creation of a Cabinet-level Department of Science and Technology. Federal R&D funding that is not earmarked for defense represents a taxpayer investment of more than $18 billion annually. But it's an investment from which we don't reap enough reward. Federal efforts are scattered throughout several organizations and some 700 different federal labs. By one count, there are some 2700 distinct federal R&D program elements that receive line-by-line budget scrutiny from 54 different congressional committees and subcommittees—a managerial maze through which few scientists are equipped to steer.

We also called for permanent tax credits to stimulate more research and development by industry. R&D tax credits are preferable to project direction by the government, we believe, because they allow the most knowledgeable players in the market to determine which technologies have commercial potential. And while some may question our recommendation for R&D tax credits in a year when cutting the federal deficit is a key goal, I think it can be demonstrated that today's investment in R&D will produce for government a far greater gain in revenue. Industries that do R&D tend to perform better than those that don't. They create more jobs, achieve better balances on the trade ledger, and provide more tax revenues to Uncle Sam.

In addition to improving our creation of technology, we must do a lot better at applying it. This nation's most glaring weakness in technology may well be its failure to devote enough attention to manufacturing. Our manufacturing engineers have generally been paid less than people in marketing or R&D, and you can count on one hand the universities doing research in process technology and manufacturing management. It does us little good to generate state-of-the-art designs if someone abroad can then copy and manufacture the products at much lower cost.

Capital ideas. Even if we dramatically enhance our abilities both to create and apply technology, those improvements could be to no effect if we've neglected another critical area: capital resources.

To anyone but a banker, that word *capital* doesn't evoke fond feelings. Nevertheless, capital is the fuel for our economic machine; there's a definite correlation between a nation's level of investment and its growth in productivity. If you rank our six major trading partners on capital formation, that

listing will almost exactly mirror their ranking in productivity growth. Japan is at the top of both rankings, by the way, and the U.S. is at the bottom.

As the commission investigated reasons for the low level of U.S. investment, one of our greatest surprises was to find that a wide range of economists actually agreed! Their consensus: High capital costs give American firms a serious competitive disadvantage; their costs are at least twice as high as those of their Japanese counterparts, for example. In fact, many studies have concluded that lower capital cost—not technological supremacy—was the prime factor behind the Japanese incursion into the markets previously dominated by the U.S. semiconductor industry.

If we're going to reduce the cost of capital to American industry, we'll first have to cut the deficit. Federal borrowing not only puts government in competition with industry for scarce capital resources but also pushes up interest rates and strengthens the dollar. Since 1980, the value of the dollar has almost doubled compared to the major European currencies. For companies trying to sell in international markets, this means higher prices for our exports and fewer sales abroad.

Second, our tax system must be restructured. It is currently a "de facto" industrial policy and a bad one. It discourages saving, encourages borrowing, and weighs most heavily on the sector of our economy that faces the greatest international competition—manufacturing.

In order for Congress to analyze the diverse collection of tax reform proposals now under consideration, the commission proposed criteria for judging the consequences of each on the nation's ability to compete. One criterion, for example, was the relatively impartial tax treatment of different industries and kinds of assets. We also recommended ways of encouraging investment—such as inflation indexing for capital gains and fuller deductions for capital losses on individual income tax returns.

A third way to lower the cost of capital to American firms is to pursue a more stable monetary policy. The graphs in our final report that plot the variations in consumer price index and prime interest rates since 1971 look like roller coasters with jagged peaks. Unstable monetary policy adds to high capital costs because it forces lenders to add risk premiums to their loans. Thus to those who blame American business for its short-term investment perspectives, I say that there's a reasonable excuse. It's pretty hard to do long-term planning and investment in a wildly changing business environment where few lenders would put out a 20-year note. High capital costs force a short-term outlook.

Human resources. If capital is the fuel for our economy, people are the drivers. And one of our critical challenges is to help the American workforce respond to changing markets and technology. Fully three-fourths of those people who will be employed in the year 2000 are already working. No matter what the industry or the job category, people are going to need training and retraining.

As a nation, we must rid ourselves of the idea that education takes place only during a short period of our lives. Learning should be a lifelong process,

This nation's most glaring weakness in technology may well be its failure to devote enough attention to manufacturing

and the commission made some recommendations in that spirit.

First, the ability of our educational system to provide vocational training for adults must be strengthened. Currently, almost half the people who take job-related courses are high-school graduates, yet only 19% of federal funding for vocational education serves that group. Thus the portion of federal monies earmarked for adult education should be increased.

We also recommended a variety of practical steps that could be taken to assist displaced workers with better job-search and retraining services. Some suggestions involve improved efficiency, such as streamlining the U.S. Employment Service. Others involve new approaches, such as allowing displaced workers to use their unemployment benefits as vouchers—wage subsidies, in effect—for employers who would hire and train them.

Finally, we recommended that future tax restructuring should address industry investments in human and capital assets more evenly. America's workforce is highly mobile, and that's a competitive advantage for us. But mobility sometimes makes a business's training expenses hard to justify to stockholders. We should therefore take care not to create any tax disincentives to employer investment in training.

Fair trade. The fourth and final area that the commission explored was international trade, and we concluded that it simply has not been a great national priority. Responsibility for trade policy is splintered. There's the Commerce Department on one side and the U.S. Trade Representative on the other, with various pieces of the action owned by the Departments of Defense, Treasury, Agriculture, and State, as well as a host of other executive agencies and congressional committees. This complexity and lack of accountability led us to recommend the creation of a Cabinet-level Department of Trade to provide a single strong voice for trade issues. We were encouraged to hear President Reagan endorse the move in his State of the Union address, and I am told that a White House task force has been formed for this purpose.

Here are some other things we should do to get our house in order:

First, we need a new omnibus trade bill that provides ways to help U.S. industry adjust to international competition before the damage is irreparable. That bill should also clarify how we intend to respond to the industrial targeting procedures of our trading partners.

Second, we must search for a more uniform approach to export controls. We often prohibit the export of technology that our allies consider allowable. The commission heard testimony that put the cost of our stricter rules at more than $12 billion in lost U.S. sales

each year. For technology that we do allow for export, we need to streamline the licensing process. It takes American exporters far longer to get licenses than their competitors abroad.

Finally, we should be looking for ways to encourage U.S. exports. These include more competitive export financing, better information about foreign markets, and the active support of U.S. embassies abroad.

As we looked at the international trade environment in which American business operates, we saw two trends going on simultaneously—and pointing in opposite directions. On the one hand, the total volume of world trade has grown enormously—sevenfold since 1970. On the other, the portion of that trade covered by agreed-upon rules has shrunk dramatically. There's no coverage for trade in services or investments. There's little provision for agriculture or state-owned industries. And while tariffs have come down, the use of nontariff barriers has increased significantly.

Like American trade law, international rules haven't yet responded to targeting policies and nontariff barriers. And the newly industrializing nations' commitment to the rules is weak at best. We must strengthen the international trading system by increasing the kinds of practices and the amount of trade it covers. And we should get our trading partners—especially the newly industrializing countries—to commit to its rules.

Back to basics. I am sometimes asked to choose our "main" recommendation. I refuse to do this, because I don't believe that our competitiveness can be improved with just one act. That's like saying that a business can succeed just by better managing its inventory—while ignoring R&D, accounts receivable, employee development, and the rest of its activities.

We've also heard that some people were disappointed that the commission didn't come up with "anything really new." It's true that we haven't identified any new roles for government, primarily because it became clear to us that government has yet to adequately perform the roles it already has. Government is responsible for creating an environment within which American business can effectively compete. This basic goal has not been fulfilled.

Our call for renewed attention to the fundamentals also applies to those of us in the private sector. The ultimate responsibility for being competitive rests with us. The foresight of our strategies, our responsiveness to customers, the cost and quality of our products, and the commitment to developing our workforce all affect our performance far more than anything government can do for us. These challenges aren't new, but we must address them with new vigor.

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MARKETING VOICE MAIL WITH IBM



ROBERT ISAACS

Rolm joined IBM's ranks but kept its own marketing, legal, and financial reporting practices, says Rolm's Jeff Crowe (shown here at company headquarters).

After IBM purchased Rolm last November for $1.26 billion, the world's biggest computer company quickly streamlined its new entrepreneurial subsidiary—a maker of private telephone switching equipment—by selling off the military computer division. But otherwise, the Santa Clara, Cal., company was left outwardly unchanged. Then, in April, IBM and Rolm made twin announcements that simultaneously expanded Rolm's markets and tucked it more securely under IBM's wing. Rolm announced a new version of its PhoneMail voice messaging system—previously compatible only with its own private branch exchange (PBX)—that will now work with other vendors' PBXs or Centrex systems. And IBM announced it will stop selling its own voice messaging system in the U.S. and Canada in favor of PhoneMail.

Voice messaging systems, first commercially available in the early '80s, record and play back phone messages that a user can then erase, save, or forward to others in the network. Most systems let users retrieve messages from their individual "mailboxes" when away from the office by calling in and entering a password from a touch-tone phone. Although the still small U.S. market generated revenues of only $100 million in 1984, it is growing steadily, according to Probe Research (Morristown, N.J.), and Rolm, with a 23% share, is the market leader. Probe VP Carl Kozarsky predicts that, with the new PhoneMail version and access to IBM's vast sales force, Rolm will extend its lead "by a considerable degree." (The new PhoneMail version needs additional hardware, though, making its starting price of $67,000 higher than the original model's $45,000.)

Although PhoneMail is the only Rolm product now handled by IBM's sales force, says PhoneMail product manager Jeff Crowe, the subsidiary hopes new sales will lead to increased business for its entire product line—led by an advanced digital PBX that can coordinate both voice and data traffic. Meanwhile, IBM will continue making and selling its own ADS messaging system in Europe, he says, because lengthy government certification processes make PhoneMail as yet unavailable there.

Paradoxically, Rolm's original decision to tailor PhoneMail to its own PBX gave it "a favored position in the market," says consultant Donald Van Doren of Vanguard Telecommunications (Randolph, N.J.). This integrated design better exploited the PBX's power, giving PhoneMail popular features—letting outside callers leave messages and using lights on phones to signal a waiting message—that generic systems from competitors such as VMX, Wang, and IBM couldn't match. As a result, "Rolm shot to the head of the pack in installed customer base," says Van Doren. Although some competitors now supply these features, PhoneMail is still considered one of the easiest systems to use.

However, a major obstacle to sales, says market analyst Robert Fleming of the Gartner Group (Stamford, Conn.), is that a customer must be willing to make a "huge up-front investment." Voice messaging can add 10–20% to the price of a PBX, which may already cost as much as $1000 a line. And the investment cannot easily be cost-justified, Fleming contends, because it is difficult, if not impossible, to determine how much money a company saves by eliminating unproductive phone calls.

Yet PhoneMail may owe a measure of its success to Rolm's recognition of this difficulty. Rather than focusing on the biggest companies (which ordinarily make up the initial market for expensive equipment), Rolm has targeted professional service companies, such as law, market research, and brokerage firms. "For companies selling their employees' knowledge, it's obvious that time is money," says Rolm's Crowe. Even though some firms are so small that installing PhoneMail costs far more than an extra 20% per PBX line, "they gobble it up," he says. For example, analysts from the Yankee Group, a 70-employee Boston market research firm, are highly satisfied with



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their PhoneMail system. "I think I speak for everyone here when I say we'd kill for it," declares analyst Amy Smith. "We justify it in terms of increased productivity."

But even a booster like Smith acknowledges that demand for voice messaging will have to become far more widespread for the market to grow significantly. Meanwhile, Rolm will continue to depend on PBX sales for the lion's share of its revenues, which it reported as $660 million in fiscal 1984. And observers speculate that the Rolm PBX will also play a key role in the larger arena of its parent's business plan—both to help position IBM against emerging rival AT&T and possibly to tie IBM personal computers together in officewide networks.

—Sarah Glazer

Imatron: MAKING X-RAY MOVIES

For the 1.5 million people each year who suffer heart attacks, having an angiogram to evaluate the extent of heart damage is not a pleasant prospect. A physician cuts a large artery in the thigh, snakes a catheter through it to the aorta, and injects dye into the heart to enhance the contrast of an x-ray image. As the dye flows through coronary arteries, cardiologists can accurately evaluate blood flow and pinpoint blockages. But cost and risk limit the procedure to patients at advanced stages of disease.

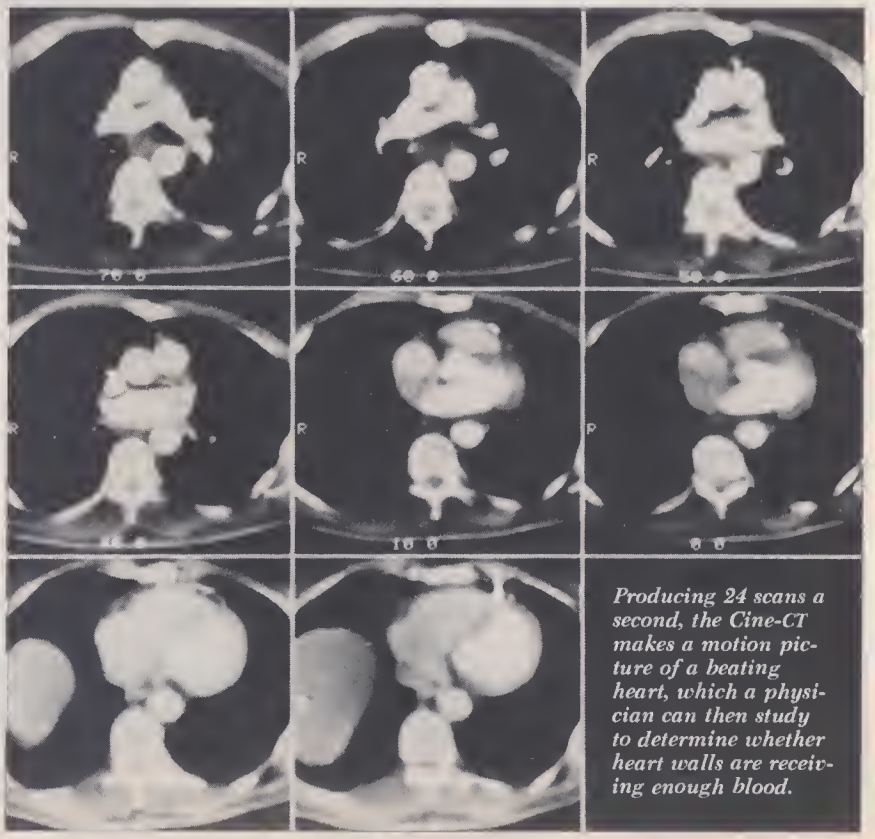
Now, a new CT scanner that can take x-rays so fast it visually "stops" the heart in mid-beat promises to eliminate angiography for some patients. Developed by Imatron, a small company in South San Francisco, the Cine-CT produces 24 scans a second, instead of about one per second for conventional CT scanners. What results is a moving picture of the heart (thus the name *Cine*) that allows doctors to see a heart wall thicken as it beats and determine whether it is getting enough oxygen.

Priced at $1.6 million, the Cine-CT is far more expensive than conventional CT scanners. But the new system eliminates the need for catheterization in its cardiac tests, reducing the price of an examination to $300–$500—one-fourth that of the average angiogram, even without taking into account the cost of a longer hospital stay. Although researchers have developed noninvasive cardiac tests based on other scanning technologies, such as nuclear magnetic resonance, positron emission tomography, and ultrasound, Imatron is hoping that its method will become the noninvasive "gold standard"—the test that consistently gives the highest-quality results.

What's more likely, say physicians testing five prototype units in New Jersey, California, and Iowa hospitals, is that the Cine-CT will become the equipment of choice for analyzing some, but not all, types of heart problems. It's especially well suited to evaluating myocardial blood flow—showing if heart walls are receiving enough blood to pump efficiently. But the machine doesn't have high enough resolution to study coronary arteries directly, says Bruce Bundage, chief of cardiology at the Chicago teaching hospital of the University of Illinois. (He has examined 200 patients with the Cine-CT in its first six months of testing.) Another drawback is that, like all x-ray equipment, it exposes patients to potentially harmful radiation. But a major advantage is the machine's speed. "We could grease the skids and do a study in 20 minutes," says Bundage.

The key to the Cine-CT's speed is that the unit produces x-rays from a magnetically rotated electron beam rather than a mechanically rotated x-ray tube, explains Douglas Boyd, Imatron's founder and chairman. An electron gun shoots a beam of accelerated electrons that, as it rotates, hits four tungsten rings, making each emit a fan-shaped beam of x-rays. In each sweep of the electron beam, the x-ray fans can produce images of a region 8 centimeters wide—large enough to include nearly all of a typical human heart. A computer then reconstructs data received from x-ray detectors into images on a screen.

Boyd began developing the Cine-CT when he was a professor at UC San Francisco. (The University of California shares the patent for the original Cine-CT, although Imatron holds several other patents for the current model and has another dozen pending.) Boyd started Imatron in 1976 with seed funding from the National Institutes of Health. Looking for capital to commercialize his invention, he tried medical technology firms; unsuccessful, he eventually found a partner—Emerson Radio—in an unrelated business. Emerson invested $1.5 million in 1981 and still owns 18% of the company. In 1983 Imatron went public, rais-



Producing 24 scans a second, the Cine-CT makes a motion picture of a beating heart, which a physician can then study to determine whether heart walls are receiving enough blood.

ing an additional $30 million.

Imatron has spent $8–10 million developing its product and last year reported a loss of $5.5 million on sales of $2.4 million. Boyd expects a "small loss" again this year, even though the company has already announced orders for three more systems this spring.

Furthermore, federal rules set in 1983 to change reimbursement practices for Medicare charges may put a damper on Imatron's growth. Jim McCamant, editor of the *Medical Technology Stock Letter* (San Francisco), says the standardization of payments for hundreds of routine medical procedures has made hospitals "much more careful" about purchases, thereby hurting vendors of expensive equipment, especially young companies like Imatron.

But eliminating the cost-plus method of calculating charges could eventually work in Imatron's favor; hospitals that are more efficient than the norm get to pocket the money they save. Since more tests are possible per day with the Cine-CT, buyers could more rapidly recoup the machine's cost. Still, Imatron's immediate market will probably be limited to very large hospitals and medical diagnostic clinics, the only places rich enough to show x-ray movies.—***Theresa Engstrom***

Microrim:
SHAKING UP THE DATABASE MARKET

Buyers of microcomputer software are notoriously stubborn when it comes to changing their loyalties. In the word processing market, the proponents of the Wordstar package are legion, and competitors have only recently been able to lure them away. The same is true of Lotus 1-2-3 in the spreadsheet realm. And the dBase product line from Ashton-Tate (Culver City, Cal.) has long reigned supreme in microcomputer database management. But Ashton-Tate may be glancing nervously over its shoulder at Microrim (Bellevue, Wash.), which has launched a campaign to end the dBase hegemony.

Microrim introduced R:base 5000—an improved version of its moderately successful R:base 4000 database manager—at the beginning of May and claims that the new $700 package is more powerful and has more features than the similarly priced top-of-the-line dBase III. The company has a long way to go to catch up with market leader Ashton-Tate, even though analysts expect the market to expand as personal computer users seek ways to organize the growing amounts of information stored in their machines. Microrim estimates that Ashton-Tate supplies 60% of sophisticated database management systems for personal computers, versus its own second-place share of 15%. A survey by Future Computing (Richardson, Tex.) of the total database market, including low-priced, unsophisticated products, gives Ashton-Tate a 20% share, versus Microrim's 4%.

Prior to introducing R:base 5000, Microrim had sold about 90,000 units of all its software packages combined. (In addition to R:base 4000—the big revenue generator—these include the R:base 6000 multiuser package, the Clout natural-language query package, and the File Gateway utility program for converting data from other programs into an R:base format.) But the company expects even bigger things from its new package. "Our goal is to sell 100,000 copies of R:base 5000 within the first 12 months of its availability," says Kent L. Johnson, president and chief operating officer, "and to double or triple the size of our company over the next 12 to 18 months."

Microrim expects R:base 5000 to distinguish itself in part through a module called Application Express, designed for both novice and experienced users. "People buy database management systems to get a tool with which they can build their own applications," says Wayne J. Erickson, chairman and chief executive officer of Microrim. "With the Application Express, we're providing a package that does the tasks usually performed by a professional system builder."



Microrim's Kent L. Johnson (left) and Wayne J. Erickson hope a contest for dealers will stimulate sales of their new software.

This feature is helping tip the balance toward making R:base a standard in the Bank Operations Division of the Shawmut Bank of Boston, says corporate services officer Mark Skeel. Although the division's 1200 employees now use a variety of packages, he says, "we're very impressed with the features of the Application Express. Instead of having to conceptualize what a database is and what fields [column headings] are, Microrim has developed some visual aids to help people easily understand it."

Microrim's Johnson stresses that large customers like Shawmut Bank represent a major market to Microrim, which sells its products to retail chains and to distributors, which resell them to individual dealers. "Our objective is to make 50% of our R:base 5000 sales to Fortune 2000 companies, with the remaining 50% to small and medium-sized firms."

But as with most microcomputer software, success ultimately depends on drawing customers into stores and convincing dealers to push the product. To bring in customers, Microrim will rely heavily on a $9.95 tutorial disk that gives buyers a taste of R:base 5000's features. This strategy proved so successful with R:base 4000 that 37% of tutorial buyers went on to buy the full product. The company is also running an extensive advertising campaign targeted, as usual, against its archrival, Ashton-Tate.

To enlist the support of salespeople and store managers, Microrim established a 90-day dealer incentive program (May 1 to July 31). Salespeople get $500 for every 25 packages they sell, and managers get $5000 if their store sells more than 100 copies. The top 30 managers and the top 10 salespeople each win an all-expense-paid trip for two to Japan. With almost half of Microrim's 3000 dealers signed up to participate, the company hopes sales will start off with a bang. In an unusual twist, Microrim plans to send contest information to participants' home addresses. "We realized that the second most influential salesperson was the spouse," explains Johnson. "Therefore we're making this a family affair."

—***Dwight Davis***

PARALLEL PROCESSING GETS DOWN TO BUSINESS

For years, the designers of highly parallel computers—those with hundreds or thousands of processors working together on a single problem—have been like "composers describing how wonderful their symphonies are before they are ever performed," in the words of one researcher. While hundreds of theoretical designs existed, no such machine had been built. Now years of research are starting to pay off, with a number of parallel computers being built, tested, and even sold commercially. These computers and others likely to appear during the next 18 months will begin to answer some of the questions that have long plagued this area: Can parallel processors actually top the speeds of more conventional supercomputers? How hard will they be to program? What designs will succeed?

The activity in the parallel processing market began to heat up about a year ago. The current projects not only signal an enthusiasm for parallel architectures but also illustrate differences of opinion about how many processors are most effectively linked within a single machine. NASA's Goddard Space Flight Center already uses a limited-application computer, the Massively Parallel Processor—built by Goodyear Aerospace (Akron, Ohio)—with over 16,000 subprocessors. For more than a year, Bolt Beranek and Newman (Cambridge, Mass.) has marketed the Butterfly multiprocessor, which can encompass more than 100 subunits, and has government contracts to build ten systems. In February, Intel Scientific Computers (Beaverton, Ore.) announced a 128-processor machine, the iPSC. In the course of this year, Thinking Machines (Cambridge, Mass.) will complete its first commercial Connection Machine with a whopping 64,000 processors. And next year the Japanese plan to complete the Sigma-1, in which a program is divided among 200 processors automatically, instead of by a programmer. Other projects will be completing full- or partial-scale machines in the same period.

While the ultimate aim of most parallel processor designers is to create extremely powerful machines that will outshine current supercomputers such as those from Cray and Control Data (both in Minneapolis), most of the initial parallel machines will compete against superminicomputers like DEC's VAX-11/780. The supermini market is potentially much larger than the specialized supercomputer field, and the first versions of most parallel machines don't yet equal the performance of the supercomputers. Still, the likely applications for future parallel processors are similar to those currently addressed by the supercomputers. The computers will be used by scientists doing simulations of weather and other complex processes, by engineers studying aerodynamic flows, and by artificial intelligence researchers designing expert systems.

Machines with hundreds or thousands of processors begin their assault on traditional computers

Why parallel? The interest in parallel computers, which dates back two decades, is based on some straightforward reasoning. Conventional serial computers, employing the basic architecture first developed by John von Neumann in the 1940s, work by taking data from a central store, operating on it, and returning it to the store. For many applications, this is an exceedingly inefficient procedure. Take, for instance, an image-processing application in which a series of 100 operations must be applied to millions of individual picture elements (pixels). A serial computer would waste most of its time repeatedly retrieving and storing a vast amount of data, with relatively little time devoted to actual computation.

By contrast, a parallel processor with, say, a processor for every 10 pixels, could take several pieces of data and perform a series of operations on them in parallel before returning them to a distributed memory; most of the time would be spent in processing. Since accessing a memory typically takes longer than processing information, the parallel computer theoretically could work far more efficiently than the von Neumann one.

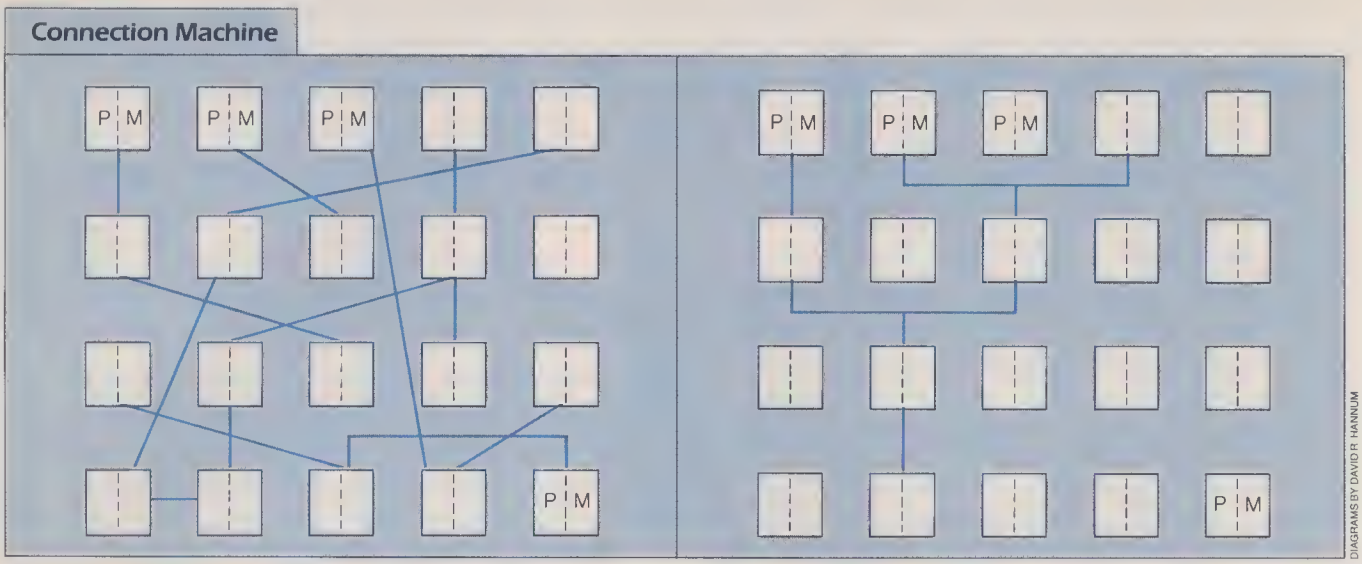
What's more, parallel multiprocessors should, in principle, cost less than von Neumann machines. The only way to speed up a serial computer is to reduce its clock (or step) time—the time between the start of one operation and the start of the next. This is what supercomputer vendors have done; their computers currently run with step times of about 10 nanoseconds and, within a few years, will drop to about 1 nanosecond. But such high-speed devices require the latest in very-large-scale integration (VLSI) semiconductor technology, as well as elaborate cooling systems. A hundred devices operating

by Eric J. Lerner

NIGEL DICKSON



A BRIGHT IDEA? *Thinking Machines' Daniel Hillis designed a computer that reconfigures itself for each task.*



Thinking Machines' Connection Machine, still under development, will contain 64,000 processors (P), each with its own dedicated memory (M). Conceptually, the machine has a 12-dimensional geometry, but links between the thousands of processors are dynamically reconfigured as required by each application. In some cases these connections may appear totally random (left); in others, such as a program with a tree structure, the connections adjust to resemble the application (right).

in parallel, each with a 100-nanosecond step, could theoretically match the power of a single 1-nanosecond device, with each costing less than a hundredth as much as the fast device.

Finally, there are clear limits to how much speed can be achieved by conventional supercomputers. Electrical signals traveling close to the speed of light can move only about 30 centimeters in 1 nanosecond, so computers with time steps at this level must be built within a one-foot cube lest their speed be gobbled up in transmission delays. This size is much smaller than that of today's supercomputer central processing units, or CPUs (typically at least a meter on a side), and cooling requirements make it unlikely that such compactness can be achieved under present technologies.

The obvious way to overcome these limitations is with parallel processors, each working on a part of a large problem. Such processors, with relatively slow step times, will generate less heat and can be densely packed. At the same time, physically larger computers with high aggregate speeds can be built without transmission delays becoming a problem.

In practice, though, there are serious obstacles to realizing the benefits of parallelism. Communication among a large number of processors and the cost of the connecting hardware pose major problems. So does the task of coordinating the processors and ensuring that many of them are not idly waiting for others to give them needed results.

To overcome these problems, dozens of different architectures have been proposed. Broadly speaking, they fall into two categories: single instruction/multiple data stream (SIMD) machines and multiple instruction/multiple data stream (MIMD) machines. In SIMD machines the sequence of instruction is similar to that of a von Neumann device, but the instructions are carried out in parallel on more than one set of data by multiple processors. But not all problems have the necessary structure for SIMD. MIMD machines provide the most parallelism and flexibility, since they are not constrained by the order of instructions in a single stream, but they are harder to synchronize.

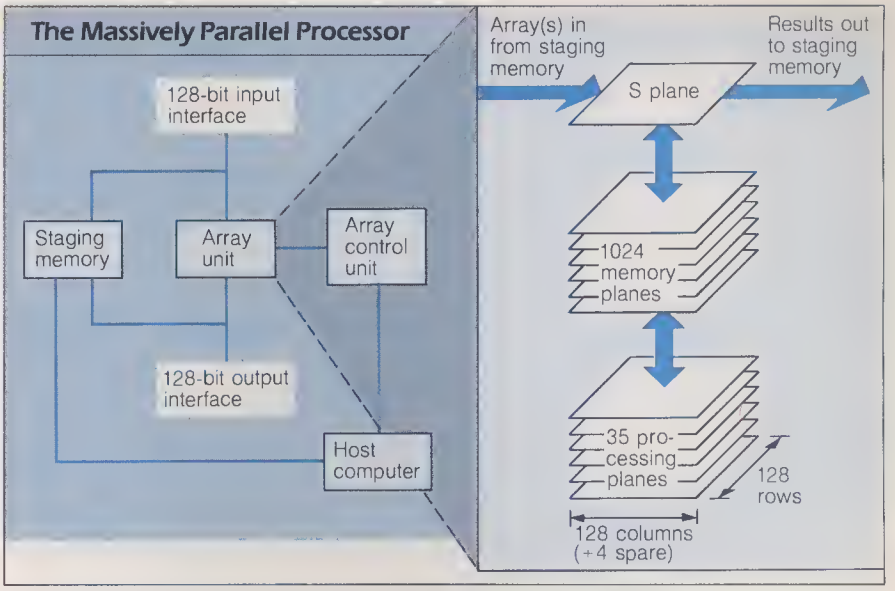
Four principal issues must be addressed in designing a parallel architecture. One is how much parallelism is desired—do you use a few dozen or a hundred powerful processors (the large-grain approach), or do you use thousands or millions of tiny processors (the small-grain approach)? A second key issue is the method of connection, especially critical with a large number of processors. High-performance connections such as crossbars (in which each processor is directly connected to every other one) reduce communication delays but are expensive and highly complex, while simple systems, such as nearest-neighbor-only connection, are cheap but constrain the system's application.

A third issue is how to attach processors to memory—will they share memory, or will each have its own? The final and perhaps most controversial issue is who decides how a problem is to be broken down into parallel parts. If this is decided entirely by the computer and its language compiler—as in the approach known as dataflow—programming is simplified, but the performance will be relatively inefficient. If the programmer must decide, performance can be optimized, but programming may become prohibitively difficult.

Until two years ago, these issues were hotly debated among parallel processing researchers, almost all based in universities. Since none of the machines had been built, though, the debates had the flavor of those medieval arguments over how many angels can dance on the head of a pin. At the same time, the whole academic parallel processor community was dismissed by those continuing to build supercomputers along more conventional lines.

Two recent developments have changed this situation. First, the supercomputer designers themselves have moved tentatively toward multiprocessors with small numbers of exceedingly fast subunits (generally fewer than ten). While such machines properly fall within the parallel processing realm, their continued emphasis on extreme power for each processor distinguishes them from the majority of new parallel machines, which rely on the aggregate power of many less expensive processing elements. Even before this move toward parallel processors, supercomputer designers had incorporated some elements of parallelism into their single-CPU designs through the use of vector processor pipelines. These architectures process strings of numbers in assembly-line fashion with several operations occurring simultaneously. The use of multiple CPUs is now taking this simple parallelism a long step forward.

Also pushing parallel computers is increased research funding. Japan's Fifth Generation and Superspeed Computing projects and the Defense Advanced Research Projects Agency's Strategic Computing Initiative have begun to spend millions of dollars to make parallel processing machines commonplace soon.



Built for NASA by Goodyear Aerospace, the Massively Parallel Processor (MPP) comprises four major modules: the array unit, staging memory, array control unit, and program and data management unit (or host). The array unit consists of 16,384 processors arranged in a 128 × 128 array (four spare columns are available if needed), with each processor connected to its four nearest neighbors. Each processing element works on 1-bit data and is composed of 35 1-bit registers. Also associated with each processing element are 1024 bits of memory, resulting in 1024 memory planes (each 128 × 128 bits) for the entire two-dimensional array. Data are stored and reformatted as necessary by the staging memory and then fed over a 128-bit-wide path to the array unit's S plane (an input/output memory facility). After 128 clock cycles, the S plane is full; its entire contents can then be stored in any available memory plane in one clock cycle. Likewise, a full memory plane's contents can be shifted to the S plane in one cycle for output to the staging memory. The array control unit sends the array's processors their identical instructions and coordinates their operation. The front-end host handles user and program interactions with the system.

Competing with Cray. Conventional supercomputers are the standards against which the new highly parallel processors will be measured. The basic question is whether massively parallel processing will produce more computing power at less cost than the products of Cray and its competitors. The Cray X-MP/48, which has four high-performance processors, is generally considered the fastest of today's supercomputers—with a theoretical maximum speed of 1000 million floating-point operations per second, or MFLOPS. (In practice, such peak speeds are rarely achieved; for most applications, processing speed is about a tenth the maximum.) The X-MP series has a clock cycle of 9.5 nanoseconds.

Yet future parallel processors will be competing not with today's supercomputers but with the even faster machines now under development. The Cray 2, a four-processor machine expected to appear this year, will have a 4-nanosecond cycle and a peak performance of up to 3 billion floating-point operations per second (gigaFLOPS or GFLOPS). In 1986, ETA (St. Paul)—a spinoff of Control Data—plans to release its GF-10, an eight-processor machine with a 10-GFLOPS capability. The Cray 3, with a 1-nanosecond cycle time and computing power comparable to the GF-10, will be introduced around the same time. Future supercomputers, like their present-day progenitors, will cost about $5–10 million each.

It seems unlikely that any of the massively parallel processors currently under construction will reach, let alone exceed, these speeds, except perhaps in limited-application areas. However, with the future 1-nanosecond machines, the supercomputer designers may be nearing the physical limits of the traditional approach. They may find it very difficult, for example, to go from 1-nanosecond cycle times to 0.1-nanosecond times. In 0.1 nanosecond an electrical signal moves only 3 centimeters—forcing an entire computer to fit within a 1-inch cube! Thus, late in this decade, highly parallel architectures could start to surpass the power of supercomputers having less than a dozen or so subunits.

SIMD is simplest. Since the SIMD approach is the simplest of the parallel designs, it should not be surprising that the first operational large-scale parallel processor was designed along these lines. The Massively Parallel Processor (MPP), built by Goodyear for NASA, is intended for work that has a high degree of inherent parallelism and "localness" (a tendency for parts of the problem to be affected only by adjacent parts). Examples are image processing and hydrodynamic modeling. In contrast, AI applications are often characterized by interactions of distant parts of a large problem.

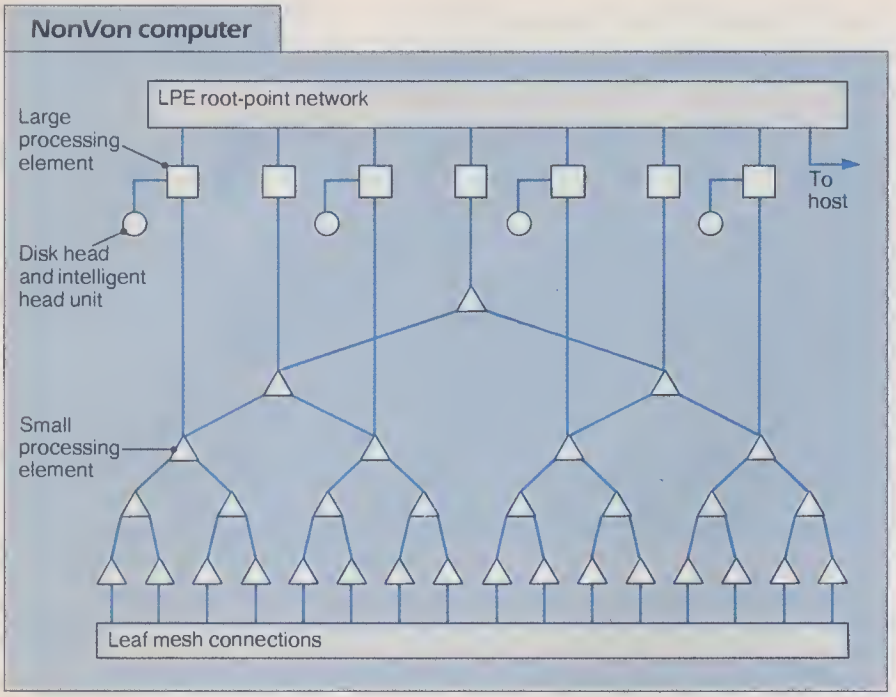
The MPP is based on a nearest-neighbor network—its 16,384 processors, arranged in a 128 × 128 square array, are each connected only to their four neighbors. The edges of the array can be connected to the opposite edges to form a cylindrical or donutlike surface.

The individual processors, which are small and simple, are combined in groups of eight on custom-designed complementary metal oxide semiconductor (CMOS) VLSI chips. Each processor is attached to 1 kilobit of memory on a standard RAM chip. The processors themselves consist of an arithmetic unit, a logic unit, and a few shift registers. Operating with a 100-nanosecond step time (10 million steps per second), each processor can add, for example, some 400,000 8-bit integers a second or do 13,000 32-bit floating-point multiplications. This gives the MPP an overall maximum rate of some 200 MFLOPS, approaching that of the fastest existing conventional supercomputers. It also makes the MPP the most powerful of the available highly parallel systems.

Collectively, the processing elements make up the array unit (ARU), the main component of the computer. The ARU processors get their identical instructions from a separate "array control unit," which broadcasts the control signals and memory addresses to all processing elements. This unit also controls input/output operations and performs scalar operations that don't require the computing power of the array. A conventional DEC VAX-11/780 acts as the front-end interface for the whole machine, accepting programs and data from the users and outputting the MPP's final results.

The array continuously performs simultaneous operations on a plane of 16,384 bits. For some applications, the performance of the MPP has been impressive. For example, in a single operation the MPP groups pixels from Landsat images according to their spectral characteristics—in effect, dividing up an image into many segments with approximately constant characteristics. On a VAX-11/780, this grouping algorithm took seven hours, while on the MPP it took only 18 seconds, or less than a thousandth as long. Since current supercomputers are considered to be one or two hundred times as fast as a VAX, the limited-application MPP appears to be 5–10 times as fast as existing supercomputers, even though its clock rate is ten times slower.

In theory, the MPP could be scaled up to have 100 times as many processors,



The NonVon computer uses both large processing elements (LPEs) and small processing elements (SPEs). The LPEs connect to each other over a high-bandwidth root-point network and connect to SPEs via treelike networks. Every LPE and SPE has its own local memory. SPEs at the bottom of the trees are connected to their nearest neighbor SPEs. Still a prototype, NonVon will theoretically grow to 8000 processors.

providing enormously faster speeds than conventional supercomputers. For many applications that can live with nearest-neighbor connections, such as fluid simulations, some computer vision applications, and image processing, the MPP's simple design may prove a significant competitor. But many applications aren't suited to the limitations imposed by this architecture.

Cellular automata. The Connection Machine, now under construction by Thinking Machines, tries to overcome these limitations by setting up a network of simple processors that can be easily reconfigured to reflect the actual structure of a given problem. The machine was originally designed for artificial intelligence applications, in which large bodies of information, such as the rules for a sophisticated expert system, have to be searched repeatedly and rapidly. (Thinking Machines now believes that the Connection Machine will prove equally effective in processing many types of scientific problems.)

In AI problems each piece of information can be represented as a node in a network, with the relations among the pieces represented by connections between the nodes. The Connection Machine tries to embody this structure in hardware. Each tiny processor has associated with it a small piece of memory, and each processor can form connections with any other one through the physical (hardwired) network. In this system a search is, in effect, the process by which connections are formed—that is, the process by which one cell finds the address or location of another cell.

For example, suppose cell RED wants to call cell BLUE. RED sends out a message wave that propagates to all cells in the network. When the wave, which contains RED's address, reaches BLUE, the BLUE cell sends its own address back to RED. The RED cell then cancels the still-spreading message wave with a faster cancel wave. The cancel wave travels faster than the message wave because the machine uses built-in delays to slow the initial message wave.

Messages are transferred from cell to cell, and each cell alters the instructions appropriately as it passes them along. Thus a message with an address "up 2, across 5" could be given to the cell above, with the address altered to "up 1, across 5." And since pieces of information can be moved from cell to cell, those that are closely related logically can be stored in neighboring cells, thus minimizing delays.

The machine is based on the concept of cellular automata, tiny entities that communicate with their neighbors in some prescribed fashion and that have become familiar to computer users through such games as "Life." Says Daniel Hillis, the machine's principal designer, "The main advantage of the Connection Machine is its flexibility, the way in which the networks can be made to reflect the problem."

The machine under construction, to be completed this year, will contain 64,000 small processors. Even though its cycle time will be only 1 microsecond, or 10 times slower than the MPP, the Connection Machine will be similar in performance to the Goodyear machine—about 10 billion 8-bit integer operations per second. It contains about 1000 custom VLSI circuits with nearly 100,000 gates each.

The physical interconnection of the network is a variant of the "n-cube," or "hypercube," in which each processor is physically joined to a given number (n) of nearest neighbors. However, the path of data through the network is altered by the address-to-address connection formed during the running of a program, so that a "virtual network" of arbitrary topology can be constructed.

The Connection Machine is not itself a complete computer; it needs a conventional front end to feed it a serial stream of instructions. As a result, it is a SIMD machine, carrying out single instructions on a large body of data through parallel processing.

The basic idea of embedding tiny processors in a memory, in effect creating an intelligent memory, is not unique to the Connection Machine. A related idea is embodied in the NonVon, under development at Columbia University. NonVon, like the Connection Machine, is composed of several thousand (and ultimately a million or more) simple processors, each with a tiny memory.

The structure of NonVon, though, is quite different, allowing the currently planned version to run MIMD programs

Representative parallel computers

Machine	Developer	Number of processors	Cycle time (nanoseconds)	Maximum speed	Memory	Year operational
MPP	Goodyear Aerospace	16,384	100	6.5 BIPS[1]	Dist.	1983
Connection	Thinking Machines	64,000	1000	10 BIPS	Dist.	1985
NonVon	New York University	8000	1500	16 BIPS	Dist.	?
iPSC	Intel	32–128	100	2–8 MFLOPS[2]	Dist.	1985
Butterfly	Bolt Beranek and Newman	to 128	?	to 200 MIPS[3]	Shared	1984
Sigma-1	Japan's National Electrotechnical Lab	256	100	100 MFLOPS	Dist.	1986
Cedar	University of Illinois	32	100	10 MFLOPS	Shared	1985

[1]Billion instructions per second [2]Million floating-point operations per second [3]Million instructions per second

as well as SIMD. NonVon uses two types of processing units—large and small. The large processing elements (LPEs), each of which has its own memory, connect to each other by a high-bandwidth two-stage interconnection called a root point network. Each LPE sends out a stream of commands to a tree of small processing elements (SPEs), each with its own, smaller memory. The SPEs at the bottom of the tree are also interconnected in a nearest-neighbor network. The LPEs in the current design are 32-bit microprocessors (Motorola 68020s), while the SPEs are implemented on custom VLSI chips.

Like the Connection Machine, NonVon is aimed primarily at AI applications that rely on associative memories capable of being searched rapidly. An associative memory is one in which the entries are addressed by their contents, rather than by a specified location. For example, it can search for all entries containing the word *red* without examining each entry in turn. In such a search, a query from an LPE can be processed simultaneously by large numbers of SPEs, with the replies returning within a few machine cycles. NonVon's LPE-tree-SPE structure allows multiple searches to go on simultaneously in different parts of the machine, even though each SPE remains permanently linked to a single LPE.

NonVon is not as far along as the Connection Machine. Last December a 64-processor prototype began running. According to David Shaw, NonVon's chief designer, its capability is 40 million instructions per second (MIPS). "The next step is to build an 8000-processor machine with a rate of 16 billion instructions per second," he says.

Big is beautiful? MPP, the Connection Machine, and NonVon are all small-grain machines in that they aim to incorporate a million or more processors, thus breaking down problems into tiny pieces (a NonVon SPE, for example, has only a quarter kilobyte of memory). The small-grain approach targets problems with an extreme degree of parallelism. Most other parallel designs use a large- to medium-grain architecture, with prototypes having a few dozen to a few hundred processors and with ultimate goals of a few thousand.

Intel's iPSC computer, the first parallel processor to be widely marketed, is a leading example of this latter approach. The iPSC is being sold in three sizes, with 32, 64, and 128 processors each. The computer is broadly based on Caltech's Cosmic Cube machine, developed by Charles L. Seitz and Geoffrey C. Fox. (The Cosmic Cube was among the first machines to use the hybercube connection, which has since been incorporated in modified form by such computers as the Connection Machine.)



KEITH SKELTON

HORIZONTAL PROCESSING. *Ed Slaughter, general manager of the Intel Development Operation, believes the iPSC computers will give parallel processing credibility.*

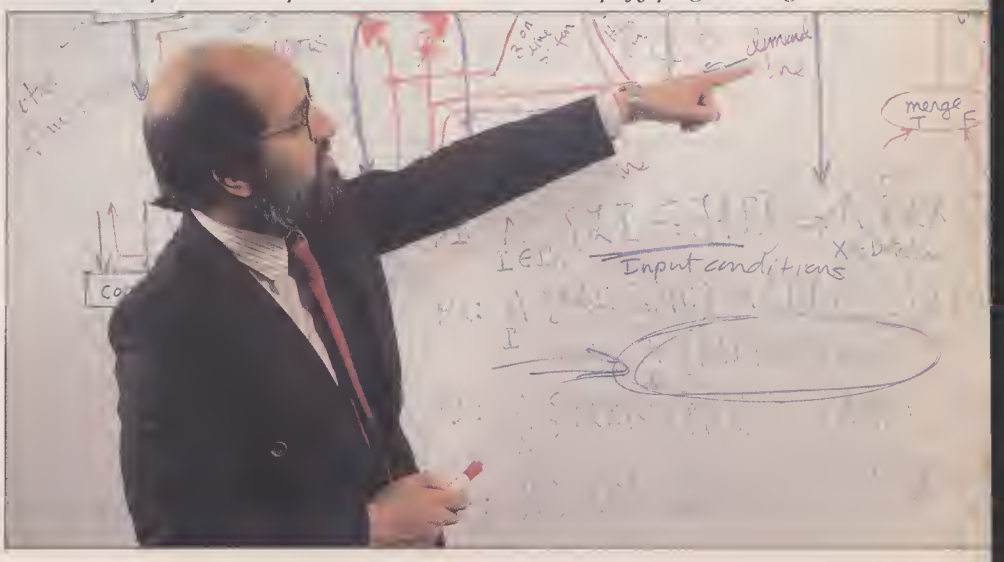
Compared with the processors of small-grain machines, the individual Intel processors are much more powerful. Each single-board processing unit contains an 80286 CPU, an 80287 numerical processor, 512 kilobytes of CMOS dynamic RAM, and 64 kilobytes of ROM. Memory capacity alone is roughly 1000 times greater than for the small-grain processors.

This larger memory is needed for the iPSC's main target applications—physical-science simulations. These currently depend heavily on floating-point operations, in contrast to AI symbolic applications. A single floating-point number requires 64 bits of storage, and the multiplication of long strings of such numbers requires considerably more. AI applications rarely call for numbers with many decimal places—8-bit integers are generally enough.

Interestingly, the dependence of scientific applications on floating-point operations may diminish as small-grain parallel machines arrive on the scene. With such massively parallel computers, the detail now provided by very large or very small floating-point numbers could instead be provided by breaking the problem into tiny pieces, explains Jim Bailey, director of marketing at Thinking Machines. "With parallel machines, the scientists will become increasingly involved with the relationship between the number of processing cells in their applications and the number of interesting elements that they're trying to understand," he says. "And as the ratio between the number of cells and the number of interesting things under study gets closer to 1:1, the capability provided by floating point becomes less of a requirement."

Floating point will still be necessary for simulations in which there are far fewer "interesting" items than processing cells, says Bailey. For example, although a computer model of the planets

GOING WITH THE FLOW. *MIT's Arvind says the dataflow technique can coordinate the numerous processors in parallel machines and can simplify programming.*



RICK FRIEDMAN

Parallel machines take on supercomputers



Schmidt



Gaertner

"The acceptance of parallel computers rests in part on the development of appropriate software. For this to occur, programmers must undergo a cultural transition."

Gary Schmidt
Manager, Parallel Processing Applications
Bolt Beranek and Newman

"Eventually, every customer for Cray supercomputers will be a customer for a Cray parallel processing machine."

Robert Gaertner
VP, Communications
Cray Research

Parallel processors—computers able to work on different parts of a problem concurrently—are appearing in the marketplace. They don't yet have the power or speed of the most advanced supercomputers working at peak operations, but they portend significant competition because of their potential for handling problems too complex for conventional machines.

The supercomputer market suggests the demand that could develop for parallel processors. Expected supercomputer sales for 1985 are $425 million, with revenue growth of 30% a year anticipated to yield $1.5 billion by 1990, says Jeffry Canin, senior technology analyst at Hambrecht & Quist (San Francisco).

A number of companies have produced, or plan to introduce, parallel processors available for purchase. Industry observers differ about who is selling "true" parallel machines, but a reasonably wide net would take in Intel Scientific Computers (Beaverton, Ore.), Denelcor (Aurora, Colo.), Floating Point Systems (Beaverton, Ore.), ELXSI (San Jose), and Thinking Machines (Cambridge, Mass.), which plans to deliver a product this year funded in part by a $3 million contract from the Pentagon's Defense Advanced Research Projects Agency (DARPA). Bolt Beranek and Newman (Cambridge, Mass.), which was awarded a $20 million contract from DARPA, is also seriously considering putting a machine into commercial production, and Goodyear Aerospace (Akron, Ohio) is open to negotiated sales for a parallel computer similar to the one it delivered to NASA in 1983. Cray Research (Minneapolis), the powerhouse of supercomputing, offers a multiprocessor machine that carries out parallel-like functions, while ETA Systems (St. Paul), Alliant Computer Systems (Acton, Mass.), and Encore Computer (Wellesley, Mass.) intend to introduce computers over the next two years capable of varying degrees of parallelism.

Several Japanese firms produce supercomputers, but none yet sells a parallel machine, although intensive research on this subject is under way. IBM, which is also investigating parallel processing, recently donated $30 million in equipment and services to an advanced supercomputing center at Cornell, funded by the National Science Foundation, that will explore the capabilities of highly parallel machines.

Two forces are prompting the commercial development of parallel processors. "We are running up against fundamental physical barriers in designing von Neumann machines," points out David Shaw, director of the NonVon Supercomputer Project at Columbia University (New York). "Traditional supercomputer architects are now dealing with speed-of-light limitations and exotic cooling technologies, but their efforts are reaching the point of diminishing returns." And Roy Coppinger, marketing manager for Intel, says "both the scientific community and corporate R&D departments worry about what to do when the problems they deal with become too large for conventional supercomputers. These people need greater computational power at an affordable cost."

Initially, parallel computers will be applied to simulations and other types of modeling problems. According to Jim Bailey, marketing manager at Thinking Machines, many such applications—for example, electronic circuit design, molecular modeling, oil reservoir modeling, and airflow analysis—consist of large numbers of small elements simultaneously in flux. Although usually forced into the mold of sequential operations, these problems are particularly amenable to processing that more closely matches their inherent parallelism. Parallel computers could yield substantial economic payoffs by reducing the time needed to design and test a product or manufacturing process, such as a new drug, airplane, or automobile.

In addition, says Bailey, there are "a whole range of applications that can't be handled easily or at all by existing supercomputers that are ideal for parallel processors." These include image processing, many aspects of artificial intelligence, and the autonomous land vehicle and naval battle management system being developed under DARPA's Strategic Computing Initiative.

Vendors of parallel computers invariably cite the relatively low costs of their machines. The average price of a supercomputer is $5–10 million; most parallel models, albeit with considerably less power, cost under $1 million. As the technology matures, says Thinking Machines' Bailey, parallel computers will take over "a large portion of the expanding supercomputer market."

—Dennis Livingston

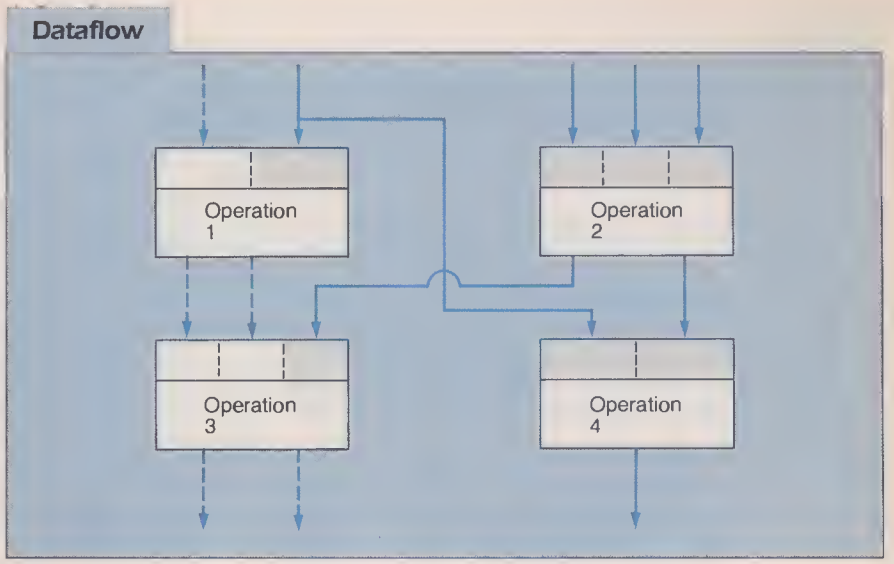
might require a billion cells to convey the size of the solar system, this huge model contains only nine interesting objects. But even for floating-point applications, he says, "I think we will find that the higher the granularity, the more appropriate the computer is for scientific applications."

Indeed, says Bailey, assigning a multithousand-cell problem to a single-CPU computer is like trying to keep thousands of corks underwater with a large sledge hammer. "In theory, if you just make that sledge hammer big enough, you can hit enough corks at the same time and drive them down far enough so you can get back to them before they bob up again. But that's a very complex algorithm. Having thousands of little hammers each hitting one cork at a time (à la small-grain parallel computers) keeps them all underwater in a much simpler fashion." Despite Bailey's enthusiasm for the small-grain approach, however, many other developers maintain that for scientific applications a large- to medium-grain architecture that employs floating-point operations will prove most successful.

Intel's iPSC, while having a relatively small number of processors, is like many of the small-grain computers in that it employs a distributed memory; each processor has its own memory and can therefore act independently on one part of the problem. How the problem is divided is determined by the programmer, not by the compiler or the computer itself. "We found that for most scientific problems, the best way to break up the problem has already been worked out," says Caltech's Seitz, "so it makes sense to have the programmer directly allocate the parts."

In the iPSC, as in the Cosmic Cube, once a part of the problem or process is allocated to a processor, it stays there. For example, in an astro- or plasma physics simulation, each processor of a 64-processor machine may be assigned one grid block in a $4 \times 4 \times 4$ grid, in turn breaking it down into finer points. During each cycle, each processor would take the field in its region, calculate the motion of the particles, and then calculate the contribution of its particles to the fields of all other grid blocks. It would then send the appropriate field contributions to each of the 63 other processors, while receiving from them their field contributions. Finally, each processor would combine the various contributions to get a new field for its region, to start the process again.

Intel claims that its new computers, sold for $225,000–$520,000, are six to 24 times as fast as a VAX-11/780 (of similar price) and a tenth as fast as a Cray 1. The 128-processor model is rated at 8 MFLOPS, or 100 MIPS.



Dataflow architectures permit asynchronous operations to fire whenever the required data (arrows) become available. The operations' output can then trigger other operations, permitting a controlled flow of processing. Here operation 1 has yet to output two data tokens required by operation 3. Operations 2 and 4 have fired, however, because all the necessary data tokens have been provided.

Sharing memory. Intel says a number of AI researchers have expressed interest in its machine, but a system with a relatively small number of separate memories does not lend itself easily to the sort of rapid searches required in AI. One solution to this problem is to use shared memories, in which the processors collectively access a single pool of memory units. The Butterfly machine from BB&N—similar to Intel's machine in other respects—uses this shared memory technique.

The Butterfly has been quietly sold to a few research groups during the past year. This May, BB&N made its first public announcement of the machine. In capability the Butterfly fits into the same niche as the iPSC, having a variable number of processors with a current maximum of 128. Each processor has access to half a megabyte of shared memory. Top machine speed is quoted at 200 MIPS, and the price is reportedly competitive with VAX's.

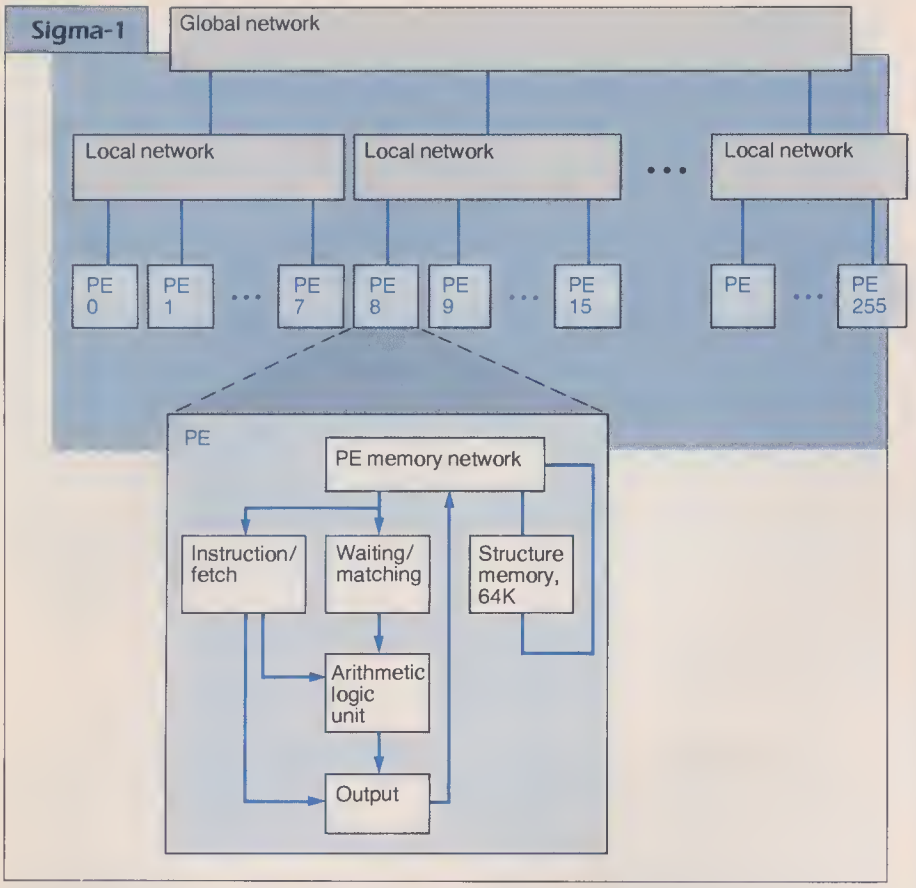
Yet it is not a direct competitor to the iPSC. With its use of shared memory, the Butterfly is aimed at the AI rather than scientific processing markets. In fact, current versions have no floating-point hardware.

Dataflow eases programming. Even if computers such as Intel's live up to their claims, traditional processors like the VAX will not necessarily lose their market. The iPSC, like all the parallel processors described so far, requires that programmers decide how a process is to be split into concurrent parts. This can make programming complex problems an even bigger headache than normal. By contrast, the sequential VAX series can run conventionally programmed problems.

The ideal parallel machine would take a standard statement of a problem and automatically convert it into an efficient implementation. This approach is the basis for a technique known as dataflow, wherein each processor receives tokens, or data packages, from other processors. When a processor has the data it needs, it performs a calculation and sends the results on to another processor. Each processor consists of a storage area with instructions on what to do with the data, a processing unit, and communication ports.

In the original implementations of dataflow machines—typified by the work of Dr. Arvind, an associate professor at MIT—virtually all of the division of a problem among the processors is done by the machine itself. A programmer uses a special language that essentially describes the problem as a map, showing the flow of the data and how they are manipulated at each point. The machine then allocates instructions among the processors, which work as data come to them.

Arvind's group is working on a software package that will emulate a prototype dataflow machine. However, a number of full-scale dataflow machines are under construction in Japan. The Sigma-1, now being developed at Japan's National Electrotechnical Laboratory, is directly based on Arvind's designs and is furthest toward completion. It is scheduled to be operational by mid-1986. The Sigma-1 will use 256 processing elements with a 100-nanosecond step time to achieve 100-MFLOPS performance on scientific problems. The processing elements are grouped into 32 subunits and connected in a



Japan's Sigma-1 will use dataflow concepts to manage the parallel operation of its 256 processors. Groups of eight processing elements (PEs) are linked via local networks, which are in turn connected by a global network. Each PE (expanded diagram) consists of a waiting and matching element that accepts data from other PEs. When all the appropriate data are available, the PE's arithmetic logic unit performs the appropriate calculation, under control of the instruction unit, and outputs the results. These travel to the next designated PE, which uses them for its own calculations.

multilevel communication network.

The Sigma-1 will be a good test of what many consider the key problem of dataflow designs: how to handle large arrays of data, a critical need in scientific applications. Difficulties arise because dataflow uses concurrency on a fine-grain level—the level of individual instructions—so data have to be moved about considerably. If entire arrays must be moved, the result is an intolerable communications overhead. If arrays are broken up, however, it is hard to put them back together. Arvind's basic solution is to leave the arrays in one place, forming a memory that is shared by all processors. This is the solution implemented in the Sigma-1, but a complex communications structure is required to keep the message flow organized and efficient.

Is it possible to strike a balance between dataflow and non-dataflow designs? Yes, according to University of Illinois researchers working on a computer project called Cedar. As in non-dataflow machines, the Cedar programmer must decide how the problems are to be divided into subtasks. But because there will be a queue of subtasks that are automatically distributed among the processors finishing their previous jobs, the programmer will not have to decide in advance the exact sequence of processing. Once inside a given processor, the chunk of the problem is handled by sequential processing, with each processor accessing a shared memory. The prototype under construction, a 32-processor machine, will have a performance of 5–10 MFLOPS.

And a cast of thousands. The machines described here are simply those closest to realization; dozens of other ideas are being worked on in university, industry, and government labs throughout the U.S., Europe, and Japan. The Reduction Machine of Gyula Mago at the University of North Carolina, for example, aims to use millions of small processors arranged in a treelike structure to carry out operations in a language called FP, developed by computer pioneer John Backus. There is also work on various types of hybrid machines, such as the Rediflow machine of Robert Keller at the University of Utah, a machine that combines reduction and dataflow ideas.

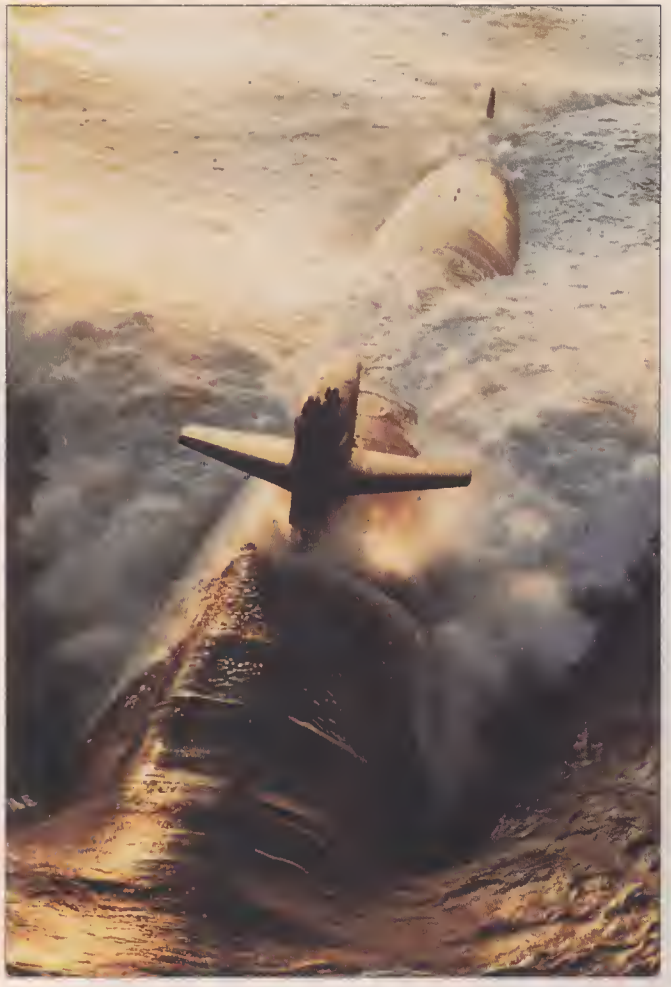
Equally significant, researchers in some AI fields such as machine vision are discovering that they don't have to buy expensive parallel computers to get the benefits of concurrency for their applications. In many cases, special-purpose processors can do the job just as fast and at a fraction of the cost. In machine vision, the most computationally intensive processes are often simple algorithms, such as edge finding, performed on all the pixels of an image. Custom VLSI chips and custom array processors can be built to expedite such operations. For example, Robert Berger and his colleagues at Carnegie-Mellon developed a special-purpose image processor with 64 subprocessors to perform a number of elementary procedures on images. It operates at a rate of 10 million pixels per second—far faster than any general-purpose computer.

The fates of the various parallel processing architectures will become much clearer during the next 18 months as researchers actually start to use and compare the machines. The Intel iPSC machine will give many users their first parallel programming experience; some researchers may then start replacing VAXs with Intel's product. Comparison between the iPSC and the Butterfly machine will give an indication of the relative merits of shared versus distributed memory. Moreover, the Cedar prototypes and the Sigma-1 will start to test the value of dataflow and the strengths of different implementations of this approach for easing programming problems. Finally, the Connection Machine will test the applicability of small-grain concurrency for both AI and scientific applications.

It is quite possible—perhaps likely—that no clear winner will emerge from all this activity. Vision researchers with a firm idea of what they need may find custom VLSI chips the best solution. AI users could wind up liking small-grain designs such as the Connection Machine or NonVon. Scientific simulation users may go with medium- to large-grain designs like the iPSC, although small-grain machines may also succeed in this market by reducing the need for floating-point operations. Those who need easy programming may opt for dataflow machines. At any rate, by 1987 there will be a wide range of choices. And by the end of the decade, successors to the current parallel machines may be giving Cray and the other traditional supercomputer vendors a run for their money. □

Eric J. Lerner is a freelance journalist who writes extensively on computer science and electronics.

For further information see **RESOURCES** *on page 72.*



COLD WAR IN THE OCEAN DEPTHS

The U.S. Navy is upgrading its sonar surveillance systems to detect quieter Soviet subs

by Jonathan B. Tucker

Twenty-four hours a day, throughout the vast expanses of the North Atlantic and North Pacific, U.S. and Soviet naval forces engage in a deadly serious game of cat-and-mouse, stalking each other's submarines with undersea listening devices, attack subs, surface ships, and patrol aircraft. The objective of this complex and costly effort is twofold: to buttress the credibility of conventional and nuclear deterrence, and to achieve tactical and strategic advantage should war ever break out.

The stakes in antisubmarine warfare (ASW) could not be higher. Because of the increasing vulnerability of land-based ICBMs, both the United States and the Soviet Union rely on ballistic missile–firing submarines as the ace in the hole for deterring nuclear war. The largest of these SSBNs (*SS* for submarine, *B* for ballistic missile, *N* for nuclear propulsion) are the U.S. *Ohio*-class Trident subs and the Soviet *Typhoon*-class subs. These vessels could wait out a first strike against land-based strategic forces and still deliver a devastating retaliatory blow. In addition to SSBNs, both superpowers possess large numbers of nuclear-powered attack submarines (SSNs), armed with torpedoes and cruise missiles that could be used against warships, aircraft carriers, other submarines, and land targets.

The submarine threat. At first glance, the Soviet Union appears to have a significant advantage over the U.S. in submarine warfare. The Soviet Navy has about 370 subs (half of them nuclear-powered, half of them diesel-powered) to the U.S. Navy's 135 (all nuclear-powered). Moreover, the Soviet attack-submarine fleet was recently augmented by some formidable new designs. The Soviet *Alfa*-class SSNs, introduced in 1980, have a superstrong titanium hull and a dense nuclear power plant, enabling them to reach speeds of 42 knots and dive to 3000 feet—considerably faster and deeper than U.S. *Los Angeles*-class SSNs. Also new to the Soviet fleet are *Mike*-class SSNs (about twice the size of the *Alfa* and also equipped with a titanium hull), *Sierra*- and *Akula*-class SSNs, and *Oscar*-class cruise-missile subs, which can launch salvos of antiship missiles at aircraft carriers from over the horizon.

These advantages are offset, however, by some prominent weaknesses. For political as well as technical reasons, the Soviets have fewer of their ballistic-missile subs at sea at any given time than the U.S., and the half of the Soviet sub fleet that is diesel-powered is limited in range. Furthermore, the U.S. Navy has long enjoyed a sizable lead in acoustic technology: American subs are much quieter than their Soviet counterparts and have more sophisticated sonars and signal-processing computers for detecting hostile submarines.

According to published accounts, U.S. nuclear subs cruising at low speed radiate only about 0.01 watt of acoustic energy—less than a car passing on a highway—and the Navy believes that they are rarely detected by Soviet sonar. In contrast, Soviet subs have achieved their impressive speeds by using high-temperature reactors with large and noisy cooling pumps. Their propulsion systems are also louder because they are reportedly not manufactured to the same fine tolerances as Western machinery. Thus when the first *Alfa*-class SSN went on sea trials off Norway in 1980, the U.S. Navy—aided by favorable ocean acoustic condi-



Ballistic missile–carrying submarines (SSBNs) are the ultimate guarantors of nuclear deterrence. The largest SSBNs are the U.S. Ohio*-class Trident (left), which has 24 missile tubes, and the Soviet* Typhoon*-class (right), which has 20. Both subs are about 560 feet long, but the* Typhoon*'s displacement of 25,000 tons is a third greater than the Trident's.*

tions—heard it in Bermuda, some 4000 miles away.

Over the past five years, however, the Soviets have made a concerted effort to apply submarine-quieting technology to their new boats (as well as some older sub classes) and thus are beginning to erode the U.S. lead. Although Soviet subs are still louder than their U.S. counterparts, a relatively small decline in the noise output of a submarine can significantly cut down the range at which long-distance sonars can detect it. "Progress in Soviet submarine quieting and sonar and signal processing improvements have reduced the acoustic advantage of Western SSNs," said Rear Admiral John L. Butts, director of Naval Intelligence, in recent testimony before a subcommittee of the Senate Armed Services Committee. "In the next decade, these programs will result in a Soviet submarine force that is predominantly nuclear-powered, operationally more flexible, and significantly better able to fight prolonged, short-range submarine engagements, especially in defense of Soviet SSBNs."

In order to respond to these advances in Soviet submarine technology, the U.S. Navy is placing renewed emphasis on undersea surveillance. "As new generations of Soviet subs come out with incremental improvements in quieting, we need to make improvements in our surveillance systems to detect them at the same range and to localize them better," says Randolph J. Steer, a former ASW analyst who now works for the U.S. Office of Management and Budget. So far, advances in submarine quieting and ASW surveillance have largely canceled each other out. But both superpowers are stepping up research, aware that a technological breakthrough in ASW could mean global supremacy in naval warfare.

ASW has therefore become a major priority of the U.S. Navy. In 1983 it spent about $13 billion on ASW programs, including $2 billion to build three more attack subs. The total came to 15% of the Navy budget, the largest share allocated to any single mission. According to a market analysis by Frost & Sullivan (New York), Navy spending on ASW will continue to grow at an annual rate of 19.8%, reaching a projected level of $26.8 billion in 1987.

Both superpowers know that a breakthrough in ASW could mean global supremacy in naval warfare.

Antisubmarine warfare is also of growing importance to other Western countries. In four incidents between the summer of 1980 and the spring of 1984, Soviet submarines and minisubs penetrated a restricted area in the vicinity of the Swedish naval base near Karlskrona. Yet except when a Soviet diesel sub ran aground in November 1981, the poorly equipped Swedish ASW forces repeatedly failed to force the intruders to the surface. Similarly, during the 1982 Falklands War—the only major naval conflict since World War II—British ASW forces were unable to detect or destroy a German-built Argentine diesel submarine, the *San Luis*, which managed to penetrate British ASW screens and fire torpedoes at the aircraft carrier *Invincible*. Although the torpedoes failed to explode, a successful attack would have crippled the British war effort.



ILLUSTRATIONS BY MARK E. ALSOP

Colored chains indicate presumed locations of the underwater hydrophone arrays making up the U.S. Navy's Sound Surveillance System (SOSUS) in the Barents and Norwegian seas and the North Atlantic. These arrays monitor Soviet subs leaving the base at Murmansk.

Acoustic surveillance. While seawater is opaque to virtually all types of electromagnetic radiation (except extremely-low-frequency radio waves and the blue-green portion of the visible spectrum), sound waves can travel over long distances through the ocean. As a result, sonar (sound navigation and ranging) remains the primary means of detecting, locating, and classifying submerged vessels.

"Passive" sonars function solely as listening devices. They consist of arrays of hydrophones—underwater microphones—that detect the noises emitted by hostile subs over a frequency range of 10–4000 hertz. Passive sonars listen for the distinctive acoustical signature, or frequency spectrum, associated with each submarine class. This signature is generated by the vibration-

al modes of the submarine's hull, drive train, and propeller. Nuclear subs also generate noise from their coolant pumps, which keep fluid circulating through the nuclear reactor at all times to prevent it from melting.

"Active" sonars work by emitting pulses of acoustic energy (pings) into the ocean and then listening for echoes reflected from the hull or wake of a hostile submarine. Although active sonar permits more precise localization of a target, the Navy tends to prefer passive sonar because it can detect enemy subs at much longer ranges and because active sonar can betray the presence of the tracking sub and render it vulnerable to attack.

The Navy also employs "bistatic" sonar, in which a surface ship emits active-sonar pings while a submerged attack submarine listens covertly to the echoes. Alternatively, a helicopter drops a depth charge, generating an intense burst of sound waves that bounce off a submarine target and are picked up by passive sonar arrays several miles away. These echoes are then processed to estimate the target's position. Although bistatic sonar reduces the vulnerability problem, it works only over a relatively short range.

Analyzing submarine noises detected by passive sonar is a difficult task, because the speed at which sound travels through water is affected by temperature, pressure, and salinity. As a result, sounds propagating long distances through the ocean are refracted and distorted by water layers of different temperatures and densities. Sound waves also reflect off the thermocline, an interface about 100 meters down where relatively warm surface water meets the frigid water of the ocean depths. The resulting multiple sound paths and acoustic "shadows" can obscure submarines from detection. Submarine noises are also obscured by the ocean background noise generated by marine life, shipping and tanker traffic, and offshore drilling.

Extracting the telltale submarine sounds from the background noise therefore requires extensive computer processing. Dedicated signal-processing computers analyze sonar data, selecting out sounds in the general frequency ranges characteristic of machinery or other man-made sources. Sophisticated algorithms then enhance the signal-to-noise ratio by sifting the constant submarine noises from the varying background noise.

The problem of picking out the submarine signal is getting harder every year because of improvements in submarine-quieting technology and increases in the background noise of the oceans. Submarine quieting has not resulted from a single breakthrough but from attention to a host of small details. Larger submarines have made it possible to isolate noisy machinery from the hull with rubber mounts and sound-absorbing insulation. In addition, propeller design has been improved, hulls streamlined to reduce turbulence, bearings and transmission gears machined with special precision, and reactor coolant pumps and turbogenerators modified to reduce noise. U.S. Trident submarines traveling at low speeds minimize noise output by turning off their coolant pumps and allowing the fluid to cool the reactor core by convection. Recently, in an effort to reduce the effectiveness of active sonars and homing torpedoes, both sides have begun covering their submarines with a layer of anechoic (sound-absorbing) foam rubber. Thicker coatings also damp some of the sub's own radiated sounds.



SOSUS hydrophone arrays laid across the ocean floor at key geographic chokepoints (top) detect Soviet submarines leaving their bases and transmit surveillance data via undersea cable to shore-based processing stations. NATO commanders then dispatch P-3C Orion patrol planes, which drop sonobuoys to pinpoint the sub.

What's more, submarine commanders may operate in ways that reduce the likelihood of acoustic detection. They may travel at low speeds for minimum noise output or exploit the acoustic shadows of undersea mountain ranges and temperature gradients. Indeed, recent oceanographic research has revealed that the oceans contain complex eddies, jet streams, and fronts like those of the atmosphere—all of which provide opportunities for concealment.

Barrier defense. U.S. ASW forces would have three missions in the event of a general East–West war: safeguarding the Atlantic and Pacific sea lines of communication employed by allied shipping, defending U.S. aircraft carriers against submarine attack, and de-

stroying Soviet missile submarines in order to minimize damage to U.S. targets in the event of escalation to nuclear war. The U.S. Navy plans to achieve all three missions through a "forward strategy" that "calls for the majority of [U.S.] attack submarines to go forward at the beginning of armed conflict, deep into Soviet waters, to sink their fleet, bottle up their massive submarine force, and now, with the advent of the Tomahawk cruise missile, threaten land bases," according to recent congressional testimony by Vice-Admiral Nils R. Thunman, deputy chief of naval operations for submarine warfare.

In peacetime, U.S. long-range sonar systems track Soviet SSNs and SSBNs around the clock, providing continuous coverage of most of the North Atlantic and the North Pacific. The monitoring begins when spy satellites detect Soviet submarines leaving their berths. In order to reach the open ocean from any major naval base in the USSR, the submarines must then transit narrow geographic "chokepoints" where Western navies have laid down long chains of passive-sonar hydrophones moored to the ocean floor. Collectively known as SOSUS (Sound Surveillance System), these arrays pick up submarine noises and transmit them by undersea cable to shore-based processing stations. The first SOSUS arrays were installed along the U.S. coasts back in 1954, and the program remains the cornerstone of the Navy's ASW effort.

In wartime, the U.S. and its allies would exploit the advantage provided by the geographic chokepoints to attack Soviet submarines leaving or returning to their bases. For example, submarines traveling from the large naval base at Murmansk to the North Atlantic would have to run a gauntlet of SOSUS arrays laid across the narrow bottlenecks between the Norwegian North Cape and Bear Island, and between Greenland, Iceland, and the United Kingdom (the GIUK Gap). East of the USSR, SOSUS arrays in the Sea of Japan and the Aleutian Islands monitor Soviet submarines moving into the North Pacific from the naval bases at Petropavlovsk and Vladivostock.

When a SOSUS array deployed across a naval chokepoint detects a hostile submarine, Navy commanders dispatch attack subs and long-range Lockheed P-3C Orion turboprop patrol planes (some 400 of which are based at naval air stations around the world) to search the area. A P-3C drops battery-powered passive sonobuoys in patterns that are likely to intersect the sub's path. Upon contact with the water, each sonobuoy deploys an omnidirectional hydrophone, which picks up acoustic signals and transmits them up to the circling aircraft. When the target submarine has been detected and classified as hostile, the P-3C drops vertical-line-array (VLA) sonobuoys equipped with a built-in compass and a string of directional hydrophones (active or passive). By correlating the relative amplitudes and Doppler shifts of the acoustic signals, the P-3C's computer triangulates the position and heading of the target and displays it to the operator.

In addition to a supply of 87 expendable sonobuoys, P-3Cs are equipped with two nonacoustic sensors: a forward-looking infrared (FLIR) scanner, which can pick up the heat signature of a nuclear sub at very close range, and a magnetic anomaly detector (MAD) enclosed in a thin fiberglass tube projecting from the aircraft's tail. This detector can pick up tiny distortions in the earth's magnetic field caused by the large mass of ferrous metal in a steel submarine hull. Because MAD has a range of only 1000 feet, the P-3C must fly about 200 feet over the ocean surface. In wartime the aircraft would use MAD to pinpoint the target and then drop lightweight homing torpedoes to destroy it. (MAD may become obsolete, however, because it cannot detect demagnetized steel subs or nonmagnetic titanium subs.)

In the U.S. Navy's budget, ASW comprises the largest share allocated to a single mission.

Upgrading SOSUS. Because Soviet *Alfa*-class SSNs can transit SOSUS chokepoints at such high speed that P-3Cs often cannot be alerted in time to track them, the Navy is upgrading the system's response time. If the improved system works as planned, acoustic data will be transmitted to a central computer station, which will automatically identify the position and class of the target submarine and disseminate this information to the P-3Cs over a satellite data link—all within three minutes of initial detection.

The Navy is also working on a new fixed passive surveillance system to supplement SOSUS. Known as the Fixed Distributed System (FDS, code name Ariadne), it will consist of hydrophones moored to the ocean floor in 10-kilometer grids at strategic chokepoints such as the GIUK Gap. The Navy has selected McDonnell Douglas Astronautics (St. Louis) as the lead contractor for designing and testing the central elements of FDS.

Unlike SOSUS, which consists of highly sophisticated hydrophones that pick up long-distance sound waves bounced off a thermal layer or the ocean floor, FDS will employ large numbers of "reliable acoustic path" (RAP) sensors, designed for ultrasensitive detection over relatively short ranges. Because these sensors will detect only submarine noises that are radiated along direct acoustic paths within a range of about a dozen miles, they should be able to pick up even extremely quiet submarines that pass within range. And while conventional hydrophones detect only a limited range of frequencies, the RAP sensors will be tuned to pick up continuous noise emissions over a wide frequency range.

The RAP sensors will be linked by fiber optic cables similar to those that AT&T is installing for long-distance telephone lines. Consisting of bundles of hair-thin optical fibers, such cables can transmit hundreds of megabits of data per second, consume less power than conventional copper cable, reduce information losses during transmission, and convey the full range of audio frequencies emitted by submarines. And since a fiber optic cable is only a few millimeters thick, a cable hundreds of miles long could be deployed by a single airplane, ship, or submarine anywhere it is needed.

Deployable surveillance. The U.S. and NATO have deployed fixed SOSUS arrays only in areas of long-term strategic interest, such as the North Atlantic and the North Pacific. Yet most defense analysts agree that the odds of a land war in Europe are low and that future conflicts are more likely to erupt in politically unstable areas of the third world near such warm, shallow seas as the Persian Gulf, the Indian Ocean, the Mediterranean, the Gulf of Mexico, and the Caribbean. "The Navy talks as though it's only fighting the Russians, but in fact it has to deal with the third world," says Norman Friedman, an ASW expert and former deputy director of national security studies at the Hudson Institute (Washington, D.C.). Friedman also warns that as unruly third world countries acquire nuclear weapons that could be delivered with small diesel submarines, the United States may have to shield itself from such terrorist attacks by maintaining control over its continental shelf.

The U.S. Navy has largely neglected the threat of diesel submarines, which run submerged on electric batteries, recharging them by cruising under diesel power on the surface or snorkeling just beneath the waves. The Navy stopped building diesels back in the 1960s because nuclear-powered subs offered greater speed, flexibility, autono-



WILLIAM JAMES WARREN

Tod Ellis, P-3 program manager at Lockheed California (Burbank) mans the cockpit of a P-3C Orion patrol plane, one of the Navy's most widely used ASW platforms. Some 400 of these aircraft are deployed at U.S. bases throughout the world. The P-3C pinpoints hostile subs with air-dropped expendable sonobuoys and, at close range, with magnetic and infrared sensors.

my, and endurance. But the Soviets, Europeans, and Chinese have continued to build new generations of diesel-electric subs and have sold them to small navies throughout the third world. Although diesel subs are limited to short ranges, they are very quiet when traveling submerged on batteries. They are also difficult to track with passive sonar because the electric motor sounds are harder to distinguish from background noise than nuclear power plants, while the diesel motor sounds can be confused with those of commercial vessels.

Most Western sonars are optimized for detecting Soviet nuclear-powered subs in the cold, deep waters of the North Atlantic and North Pacific but do not operate well in warm, shallow seas. For example, while most U.S. active sonars operate at low frequencies to maximize range, they work poorly in shallow seas because multiple echoes from the thermocline, the seabed, and the surface drown out the target signal. These conditions require the use of higher frequencies and shorter ranges, or variable-depth sonars that are trailed on a long cable beneath the thermocline.

In order to provide an ASW surveillance capability in remote tropical seas or on the U.S. continental shelf, the Navy is developing a SOSUS-like hydrophone array known as the Rapidly Deployable Surveillance System (RDSS). This system could also serve as an emergency backup if parts of SOSUS were damaged or sabotaged. RDSS will be produced in two configurations: one that can be dropped from ASW patrol aircraft and another that can be deployed covertly by submerged attack submarines. The air-dropped version of RDSS will consist of sonobuoys that moor themselves to the ocean bottom and record acoustic data. Some signal processing will be carried out in the sensor buoy; the data will then be transmitted on command to the patrol plane for real-time threat evaluation or relayed to a shore-based processing station for in-depth analysis.

RDSS has had a troubled development history. The primary contractors, Sanders Associates (Nashua, N.H.) and Westinghouse (Annapolis, Md.), have experienced numerous technical difficulties, apparently because the Navy wants to squeeze a great many sophisticated capabilities into a small, easily transportable package. On December 26, 1984, the Navy announced that it was canceling the entire RDSS program because "persistent technical problems" had caused so much delay that improved Soviet submarine quieting would largely neutralize the system's projected capabilities. Two weeks later, however, the Navy reversed its decision, saying that the cancellation had been "premature and in error" and that the program would continue at current funding levels. The official statement read: "Given the importance of the anti-submarine warfare mission, RDSS is being reexamined in conjunction with the Navy's continuing development of ASW strategy."

Mobile surveillance. Fixed sonar arrays moored to the ocean bottom can cover only a relatively limited area and hence are practical only along coastlines or narrow geographical chokepoints. The basins of the open ocean are simply too deep (an average of 2 miles)—and too wide—to be littered with fixed sensor arrays. Thus in order to enhance its detection capabilities in the open ocean and to deploy its limited tactical ASW forces more effectively, the Navy is developing a mobile surveillance apparatus called the Surveillance Towed Array Sonar System (SURTASS). The primary contractor for SURTASS is Hydroscience, a subsidiary of Whitehall Corp. (Dallas).

Scheduled for deployment by the end

Escort ASW: safeguarding surface ships

One of the U.S. Navy's most important ASW missions is protecting aircraft carriers and merchant ship convoys from enemy submarine attack. Escort ships and patrol aircraft form a defensive perimeter around the carrier or convoy, employing a mixture of active and passive sonar to detect intruding submarines within a 100-mile zone and—in wartime—destroying them before they come close enough to launch their torpedoes or antiship missiles.

In a typical escort ASW operation, a P-3C Orion patrol plane flies in a figure-eight pattern ahead of the carrier or convoy, dropping fields of sonobuoys to "sanitize" the sea lane ahead. Meanwhile, other tactical ASW platforms (including SSNs, frigates, helicopters, and carrier-based patrol aircraft) join in the hunt, each equipped with its own set of ASW sensors and weapons.

Surface ASW escort ships such as frigates are usually equipped with a high-power active/passive sonar array mounted in the bow below the waterline. These ships also tow chains of passive sonar hydrophones, called Tactical Towed Array Sonar (TACTAS). The TACTAS hydrophones detect acoustical signals from submarines underwater and transmit them through a coaxial cable to an on-board signal-processing computer. Attack submarines are also equipped with bow-mounted sonars and towed arrays.

Airborne platforms involved in escort ASW include small S-3A Viking jets based on aircraft carriers, and LAMPS (Light Airborne Multipurpose System) helicopters based on frigates and carriers. These helicopters extend the listening area of the ship and deliver ASW weapons at close range. In addition to dropping sonobuoys, the LAMPS helicopters hover over the waves and lower an active dipping sonar into the ocean to detect nearby submarines. While the current LAMPS 1 and 2 systems must radio the raw acoustic data to the mother ship for processing, the new LAMPS 3 Sikorsky Seahawk helicopters now in production will carry an advanced autonomous signal processor that will enable them to operate beyond the ship's radio horizon.

of the decade, SURTASS will consist of long plastic tubes containing hundreds of hydrophones wired together with multichannel coaxial cable. These arrays will be several hundred feet long and towed at the end of a 6000-foot cable, away from the noise of the towing vessel. SURTASS will be able to detect submarines hundreds of miles away—compared with the range of tens of miles now achieved by tactical towed arrays. Acoustic signals picked up by the SURTASS hydrophones will be sent by coaxial cable to the towing ship, where they will undergo initial processing. The data will then be transmitted via satellite relay to a shore-based processing center for further analysis and display.

In order to tow the giant SURTASS arrays, the Navy is building specialized oceangoing tugs called TAGOS, which are designed for prolonged slow-speed operation. A fleet of 12 TAGOS ships will conduct 90-day patrols, "trawling for information" over wide ocean areas. The first few TAGOS ships have been built but not yet commissioned.

Advanced sensing systems. The Navy and the Defense Advanced Research Projects Agency (DARPA) are working on a number of ultrasensitive acoustic devices for detecting quieter Soviet submarines. One way to improve the acuity of a passive sonar system is to increase the aperture (size) of the array, be it a hull-mounted sonar, towed array, or sonobuoy field. For example, large "conformal" sonars are being developed that will be mounted on a submarine's hull, conforming to its shape. The Advanced Conformal Submarine Acoustic Sensor (ACSAS) is being developed for eventual installation on the SSN-21, the next generation of attack submarines. (The first SSN-21s, requested in the fiscal year 1985 Navy budget, are scheduled to join the fleet by the mid-1990s.) The ACSAS system will probably employ a new type of hydrophone technology, such as sheets of piezoelectric plastic that generate electric currents in response to minute acoustic pressure waves. Light, flat sections of this material could be applied like wallpaper to the outside of the hull, greatly increasing the range of passive sonars.

Another new type of passive acoustic sensor is emerging from the Fiber Optic Sensor System (FOSS) program, established in 1982 by DARPA and the Navy. Optical fibers can serve as acoustic sensors because acoustic pressure waves impinging on a fiber change its refractive index, shifting the phase of laser lightwaves traveling down it. This tiny phase shift (less than one wavelength) would be detected by using beam splitters and photodetectors to measure the interference between the laser beams emerging from the sensor fiber and a shielded reference fiber.

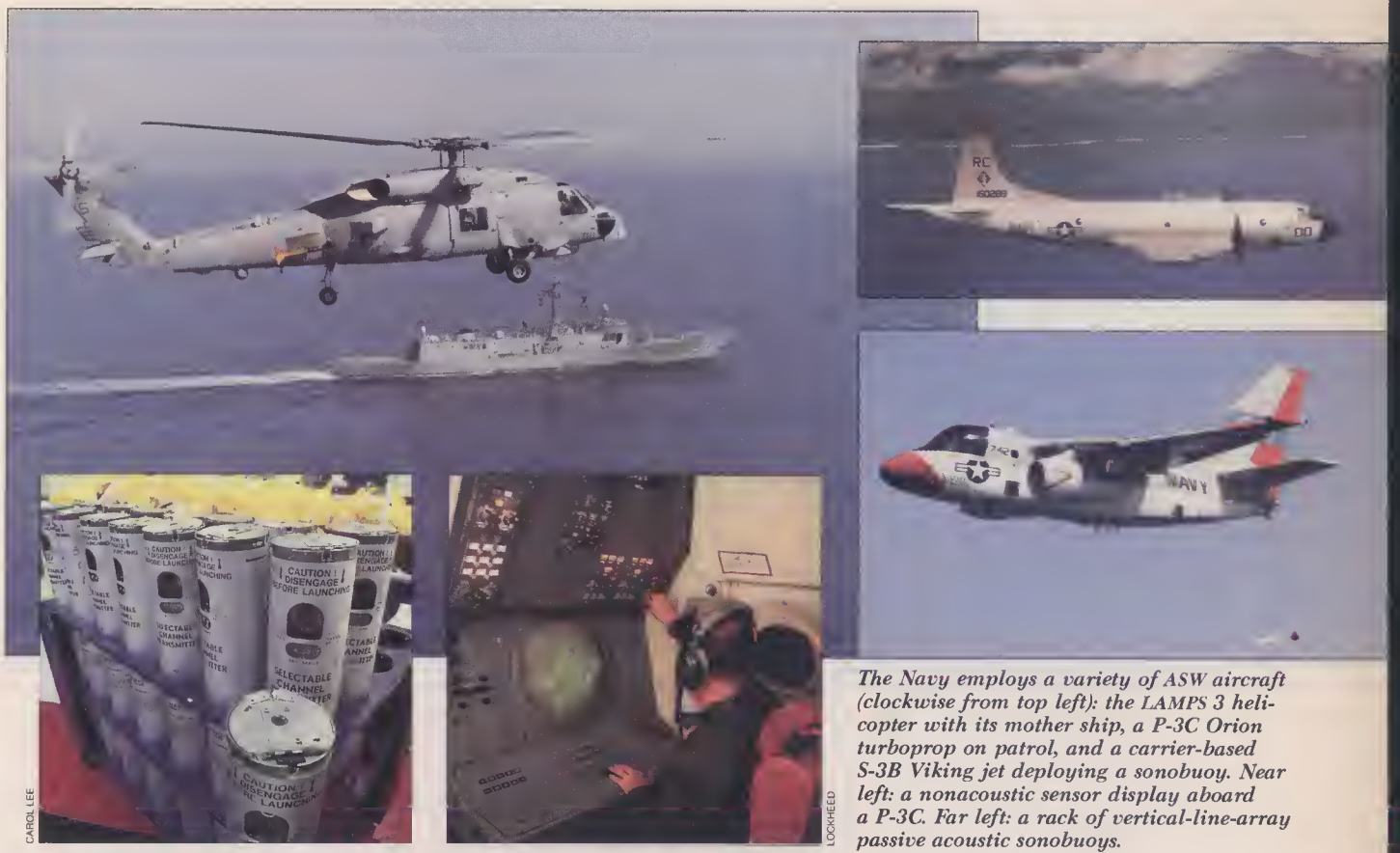
According to DARPA, fiber optic sensors would be much more sensitive than the best conventional hydrophones and would be inexpensive, lightweight, reliable, deployable at all depths, and resistant to nearby explosions, radio frequency interference, and electromagnetic pulse. Major contractors on the FOSS program include AT&T/Bell Laboratories, the Sperry Research Center (Great Neck, N.Y.), and the Naval Research Laboratory (Washington, D.C.). Prototype modules incorporating fiber optic sensors are now being tested.

In addition to improving sensor gain, another way to compensate for the weaker acoustic signal emitted by quieter subs is to use more powerful computers and signal-processing algorithms to extract the signal from the ambient noise. Since signal processing is computationally intensive, the Navy is taking full advantage of recent advances in microelectronic and optoelectronic devices and highly parallel computer architectures (in which a large number of small processors work in unison).

For tactical ASW platforms such as the P-3C patrol plane and the LAMPS 3 helicopter, IBM's Federal Systems Division (Manassas, Va.) has developed an Advanced Signal Processor that will analyze, process, and display signals received by underwater acoustic sensors in real time. The Navy is also funding basic research on an Optical Signal Processor, which would use lenses and optical switches to process data from fiber optic sensors directly, without first converting them into electronic impulses.

Signal-processing software is making great strides as well. Until recently, most Navy computers employed linear algorithms that selected out and detected submarine noises at specific frequencies or in fixed bands of frequencies. But a new technique known as adaptive sensing estimates the relative intensities and frequency spectra of the signal and the noise, and automatically adjusts the sonar array's listening "beam" and the frequencies to which it is tuned to optimize the signal-to-noise ratio. This process is repeated until the best signal has been extracted from the background noise. Eventually, adaptive processors may be able to cancel out noise from friendly submarines or surface ships, making the acoustic signatures of hostile subs stand out more clearly.

Mere detection is only the first step; one must also determine the sub's position, course, and speed. The current method is to triangulate its position by measuring the angle between the sonar



CAROL LEE

LOCKHEED

The Navy employs a variety of ASW aircraft (clockwise from top left): the LAMPS 3 helicopter with its mother ship, a P-3C Orion turboprop on patrol, and a carrier-based S-3B Viking jet deploying a sonobuoy. Near left: a nonacoustic sensor display aboard a P-3C. Far left: a rack of vertical-line-array passive acoustic sonobuoys.

and the target several times as the tracking vessel maneuvers back and forth; the Doppler shift of the sub's acoustic signal enables the processor to calculate the relative motions of the ASW platform and the target. Because this technique is very time-consuming, the Navy is developing faster methods under its Rapid Acoustic Passive Localization (RAPLOC) program. One approach is to take bearings on the target with sonars at opposite ends of a ship or submarine (such as a hull-mounted array in the bow and a towed array in the stern) and correlate the data by computer. The 1000-foot separation between the two sonars provides an adequate baseline for triangulation. When RAPLOC systems become operational toward the end of the decade, they should enable ASW forces to target hostile submarines at torpedo range (up to 8 miles) in a few minutes.

Another important area of signal-processing research is the development of automatic systems for classifying submarine noises. Typically, a sonar operator is tracking and classifying multiple sonar contacts at the same time. The signal processor extracts essential features from each sub's acoustic spectrum and displays them in visual form on a CRT screen. The sonar operator then compares these spectra with a stored library of acoustic signatures of various submarine classes. Developing an automated classification system to perform this task would free the sonar operator to analyze the relative positions and maneuvers of the detected subs. Thus, artificial intelligence researchers at Stanford, MIT, and General Dynamics are developing pattern-recognition algorithms for analyzing submarine noise spectra, as well as "expert systems" that simulate how an experienced sonar operator interprets a sub's acoustic signature.

Advances in ASW surveillance will be largely offset by improvements in submarine technology.

Yet another approach to improving the effectiveness of ASW surveillance is to integrate data from a diversity of sources, including passive and active sonars, nonacoustic sensors, and satellite images of the ocean surface. Even without breakthroughs in individual sensors, systems for "fusing" these data at a central processing station and disseminating the results to tactical forces in the field will yield significant improvements in ASW capability.

Nonacoustic ASW. Although passive sonar will remain the dominant ocean surveillance technology for both the U.S. and Soviet navies throughout the decade, acoustic detection is far from ideal. For one thing, it is losing effectiveness as submarines get quieter. For another, subs can employ active countermeasures such as acoustic jamming or free-swimming decoys that emit submarinelike sounds. "It's a measure/countermeasure problem," says Donald C. Daniel, associate professor of national security affairs at the Naval Postgraduate School (Monterey, Cal.). "Whatever ASW measure you employ, I can develop one or more countermeasures that will make life extremely difficult for you." The ultimate countermeasure might be an underwater nuclear explosion, which would generate enough reverberations to deafen U.S. passive-sonar systems for several hours—a phenomenon known as blue-out. Since the Soviet Union is less dependent on passive sonar surveillance than the U.S., it might contemplate the intentional use of underwater nuclear explosions for this purpose.

Because of the limitations of acoustic detection, both superpowers are engaged in intensive research on nonacoustic methods. Submerged nuclear submarines emit more than a dozen

Sonobuoys make a splash in ASW markets

Sonobuoys are deployed by the Navy to detect, locate, and classify hostile submarines. Dropped from the air, a sonobuoy parachutes to the water, erects an antenna, and plays out an instrument package to a predetermined depth. Acoustic data are transmitted to the anti-submarine warfare (ASW) aircraft during the brief lifetime of a buoy (8 hours or less) and then relayed to operations centers for processing and display.

The Navy will award $250–270 million in fixed-price contracts for fiscal 1985 to procure 510,000 acoustic sonobuoys, 36,000 bathythermographs (whose temperature/depth measurements aid in placing sonobuoys), and 11,000 sound-reference systems that calibrate sonobuoy emissions. There are three sonobuoy models: a $300 passive buoy, constituting 65% of the total production, that can determine the range and direction of a sound source; a more advanced passive system ($650) that uses a vertical line array of hydrophones in conjunction with directional analysis; and an active, sound-emitting buoy (under $1500) that can be turned on by the aircraft after deployment.

"Sonobuoys are the most flexible and cost-effective means for monitoring submarine traffic over large areas of the ocean on a routine basis."

G. Sherwood Smith
VP for Sensor Operation
Magnavox Electronic Systems

At least three-quarters of the sonobuoy market is shared by two firms that produce all three models—Sparton Electronics (Jackson, Mich.) and Magnavox Electronic Systems (Fort Wayne, Ind.). Other producers are Sippican Ocean Systems (Marion, Mass.), the Hermes Electronic Div. of Canadian Commercial Corp. (Dartmouth, Nova Scotia), and Rockwell's Autonetics Div. (Anaheim, Cal.). Bathythermographs are produced by Sippican, sound calibration systems by Sparton.

Several other devices are associated with sonobuoys. Reference systems that measure the position of a buoy relative to an aircraft are made by Cubic (San Diego). Hazeltine (Commack, N.Y.) and the Electronic Systems Div. of RoSPATCH (Fishers, N.Y.) produce buoy data receivers, while acoustic signal processors are manufactured by Diagnostic/Retrieval Systems (Oakland, N.J.), Magnavox, and IBM's Federal Systems Div. (Bethesda, Md.).



Heinz



Smith

The demand for sonobuoys is increasing and self-sustaining, says Michael Lauer, a VP and defense electronics specialist at Oppenheimer (New York), "because the Soviet submarine fleet, which has changed from a defensive to a world-roaming naval posture, is growing in both quantity and quality and needs to be tracked 24 hours a day." Moreover, sonobuoys are expendable, literally thrown away every time they are used. Finally, there is a particular need for more sophisticated systems able to keep up with Soviet progress in silencing techniques. Taking all these factors into account, Lauer expects that, by 1990, expenditures for sonobuoys will "probably double."

Under the "mobilization base" concept, the Navy establishes the minimum number of companies qualified to manufacture each type of buoy, according to Capt. William Heinz, program manager for air ASW acoustic systems at the Naval Air Systems Command (Washington, D.C.). This ensures that assembly lines would be available to quickly produce high-volume supplies in the event of hostilities.

There are a number of ways a company can become qualified. If the Navy wants more vendors on its lists, as it occasionally does, it will fund competitive contracts. Alternatively, a company may opt out of sonobuoy production, as did Hazeltine, whose pilot contract for the advanced passive buoy was then transferred to Sippican by mutual agreement. Or a firm could win an R&D contract, hoping to gain experience in case the buoy ever went into production. Sparton, Magnavox, Sippican, Hazeltine, and the Bendix Oceanic Div. of Allied (Westlake Village, Cal.) are working on new buoy models. But "it takes a good 5–8 years to go from first design interest to full-scale production," estimates William E. Walsh, Jr., VP for marketing at Sippican, and not many companies are able to go the distance.

"Producers of sonobuoys must compete intensively and imaginatively to meet our performance specifications at a low unit cost. We do not reward gold-plated military hardware."

Capt. William Heinz
Program Manager
Air ASW Acoustic Systems
Naval Air Systems Command

The sonobuoy club, then, is limited and relatively stable. However, buoy vendors face substantial competitive pressures among themselves, says G. Sherwood Smith, VP for sensor operation at Magnavox. A qualified company must submit bids covering a range of lot sizes for any particular model. Awards are then parceled out according to the lowest unit prices submitted for the particular lot sizes required by the Navy. Thus a company may win an award for one quantity of buoys but lose out to another firm whose price is lower for a different production rate.

The Navy does not mandate specific designs for sonobuoys; it merely announces performance specifications. "Each manufacturer can execute its own design as long as it meets the specs," says Smith. "So we are always looking at new techniques to make our designs more cost-effective. If we quit improving our designs, we would be out of the business within a few years."

—Dennis Livingston

nonacoustic signals, including infrared radiation from "plumes" of seawater heated by the sub's reactors, electromagnetic fields generated by the flow of electrically conductive seawater around the submarine hull, minute changes in the height and wave structure of the ocean surface above the moving submarine, the bioluminescence of floating plankton disturbed by the sub's passage, and discharged contaminants including trace radioactive elements, lubricants leaking from the propeller shafts, and human wastes.

Because virtually all of these signals are weak and ephemeral, nonacoustic sensors appear more practical for short-range submarine detection than for scanning wide areas of ocean. Testifying last year before the Senate Armed Services Committee, Edward Y. Harper, technical director of the Navy's SSBN Security Program, said that nonacoustic ASW "takes more than computational capability. You have to have some physical insight or breakthrough, algorithm if you like, to . . . beat down this tremendous lack of signal over noise."

Nevertheless, since a breakthrough in wide-area nonacoustic surveillance could give the superpower that first discovers it the upper hand in global naval warfare, the U.S. Navy is examining every lead, no matter how far-fetched. A number of nonacoustic devices are reportedly under development, including a magnetohydrodynamic sensor for detecting the short-range electromagnetic fields induced by a submarine's wake. Classified research is being conducted by a number of Navy laboratories and by the Johns Hopkins Applied Physics Laboratory (Laurel, Md.), Texas Instruments (Dallas), D. H. Wagner Associates (Paoli, Pa.), and TRW Space Systems (Redondo Beach, Cal.).



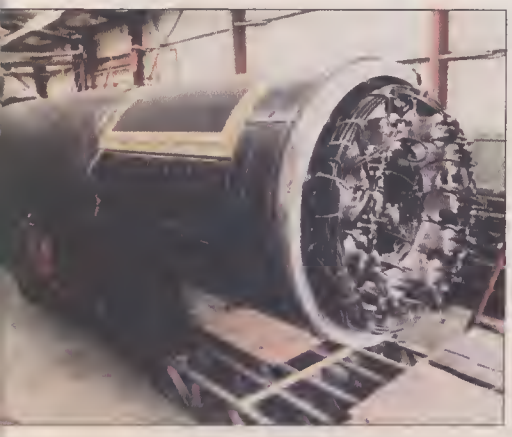
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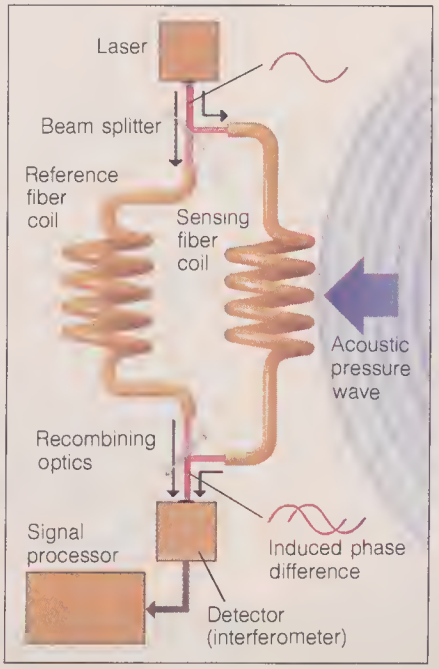
William E. Walsh, Jr. (left), and Lawrence C. Hall—executives at Sippican (Marion, Mass.)—stand with the firm's temperature-measuring buoys.

Space-based nonacoustic sensing systems are the Holy Grail of antisubmarine warfare research because of the speed at which they could scan very large swaths of ocean. Every few years a sensational story breaks in the military press about a new orbiting sensor that will make the oceans "transparent," rendering all submarines vulnerable to simultaneous attack. But to date, all such claims have turned out to be greatly exaggerated.

For example, blue-green lasers have been suggested for space-based ASW, because they emit the only type of visible light that can penetrate the ocean to any significant depth—about 300 feet. In one proposed scheme, a blue-green laser on an aircraft or satellite would scan the ocean surface, bounce off the turbulent wake of a submerged sub, and be reflected back to a detector. But such a system is impractical. While blue-green lasers may be useful for submarine communications—a broad beam could illuminate large areas of ocean—ASW surveillance would require a narrow beam that scanned back and forth repeatedly. Thus the search rate would be very low. "It would be like trying to find a five-inch wrench somewhere in Iowa at night with a flashlight," says Kosta Tsipis, director of MIT's Program in Science and Technology for International Security. Moreover, because blue-green laser light is attenuated by clouds and absorbed by microorganisms in murky seawater, the beam would probably not retain sufficient energy for the return trip.

Advanced conformal acoustic sensor being developed by DARPA and the Navy is a sheet of piezoelectric plastic that generates electric impulses in response to acoustic pressure waves. Here the sensor, surrounded by a yellow frame, is being tested on a quarter-scale model of a submarine. Fiber optic cables carry data to a processor within.





Conceptual fiber optic sensor consists of two parallel coils of optical fiber that carry beams of laser light. Acoustic pressure waves impinging on the sensing fiber induce a tiny shift in the phase of the light, which can be detected by interferometry.

Arctic ASW: Sub hunting beneath the ice

Because two of the USSR's three major naval bases are close to the Arctic Ocean, the Soviet Navy deploys many of its SSBNs and SSNs beneath the periphery of the permanent ice cap, where the ice is only a few feet thick. Cruising beneath thicker ice is difficult and hazardous because of the unpredictable amount of open space between the ice ceiling and the ocean bottom, and the danger of becoming trapped in a dead-end channel. "Under-ice operations are the one submarine activity in which the Soviets are much better than we are," says Kosta Tsipis, director of MIT's Program in Science and Technology for International Security.

The chief advantage of under-ice submarine operations is the difficulty of acoustic detection near the surface. The underside of the ice pack is extremely irregular, with giant caves and ice keels knifing down from the canopy that provide excellent places for subs to hide. Because the jagged masses of ice cause acoustic reverberation, active sonars receive confusing multiple echoes. And within one or two hundred feet of the surface, temperature gradients refract submarine noises upward, preventing them from traveling long distances. Ambient ocean noise is also very high because of the cracking and creaking of ice floes.

Nevertheless, if a target submarine is traveling well below the ice, long-range surveillance is feasible because Arctic waters provide excellent acoustic propagation at low frequencies. Although floating ice makes towed arrays impractical, self-contained sonar arrays might be deployed by patrol aircraft or attack subs.

In an East–West war, says MIT's Tsipis, a strategic reserve force of Soviet SSBNs could hide beneath the Arctic ice, surfacing through holes in the ice cap to communicate, obtain satellite navigation information, or launch their missiles. The feasibility of subpolar operations was first demonstrated in 1956, when the U.S. nuclear submarine *Nautilus* cruised beneath the North Pole. And according to *Aviation Week*, a U.S. Landsat spacecraft has photographed a Soviet missile submarine breaking through the ice in a test of this new strategic basing capability. Soviet SSBNs might also find a passage beneath the polar ice cap to firing positions north of Canada.

In order to deprive the Soviets of an Arctic "sanctuary" for their SSBNs and attack subs, the U.S. Navy is investing heavily in under-ice ASW. The Navy recently resumed submarine patrols beneath the North Pole for the first time in a decade. It is also outfitting some of its *Los Angeles*-class attack subs for Arctic operations; the diving planes on the sail, or conning tower, for example, are being reinforced with high-strength steel hardpoints for penetrating ice. The Navy also plans to build an entirely new class of attack submarines, the SSN-21 class, which will have a new propulsion system and (like Soviet submarines) diving planes on the hull rather than the sail in order to make under-ice operations easier.

The Defense Advanced Research Projects Agency (DARPA) is also working on ground-based systems for tracking Soviet submarines beneath the Arctic ice pack. On April 29, DARPA tried to launch an experimental data-relay satellite called Glomr from a Getaway Special cannister aboard the Space Shuttle, but a malfunction prevented deployment. The purpose of the mission was to demonstrate the feasibility of using a small satellite in low orbit for relaying data from small ground- and sea-based sensors. According to *Aviation Week*, ASW sensors, air-dropped into Arctic waters or even onto the ice pack, would be turned on and off by commands from the orbiting Glomr. The satellite would then record submarine surveillance data from the sensors for playback to U.S. ships or ground stations. Glomr was built for DARPA by Defense Systems (McLean, Va.) at a cost of about $1 million.

Another potential space-based ASW system that has aroused considerable interest is synthetic-aperture radar (SAR), which employs a moving satellite to simulate an extremely large radar array, yielding images of very high spatial resolution. SARs can also function at night and under all weather conditions—even clouds and fog.

In 1978, NASA launched an earth-resources satellite called Seasat with an SAR aboard. Orbiting at an altitude of about 400 miles, the radar made numerous high-resolution images of the ocean surface, typically covering an area 30×20 miles. NASA scientists were amazed when the radar images revealed subtle patterns on the ocean surface that corresponded faithfully to the topography of the ocean floor, including mid-ocean mountain ranges. The explanation: As ocean currents move over the peaks of the undersea mountains, the increased water pressure generates "internal waves"—vertical oscillations of the water column that raise the ocean surface a few inches, creating shadowy contours on SAR images.

On learning of the Seasat results, some naval analysts speculated that if internal waves from a mountain range 6000 feet down leave their mark on the ocean surface, so might a submarine 500 feet down. But in testimony before the Senate Armed Services Committee last year, the Navy's Harper said that his office had examined four Seasat images made of ocean areas where U.S. SSBNs were known to be on patrol at the time, and that none of the subs was detectable. The available SAR data are limited, however, because Seasat failed after only 100 days of its planned three-year mission.

Last September an article in *Air Force* magazine reopened the controversy by publicizing an Air Force Intelligence report on Soviet use of space-based SAR for ocean reconnaissance. The magazine said that the Soviets had carried out experiments in 1984 in which they successfully employed advanced SARs on a number of aircraft, a reconnaissance satellite, and the manned Salyut space station to detect and track Soviet *Delta*-class SSBNs operating off the Pacific coast of the USSR in relatively shallow water (200–300 feet).

MIT's Tsipis admits that SARs may be able to detect large subs underwater, but only if they are traveling fast at shallow depths. "If a submarine is almost at the surface and is tearing along at 40 knots, then you may see it," he says. "But if it's loitering at its operating depth, you won't see a damn thing."

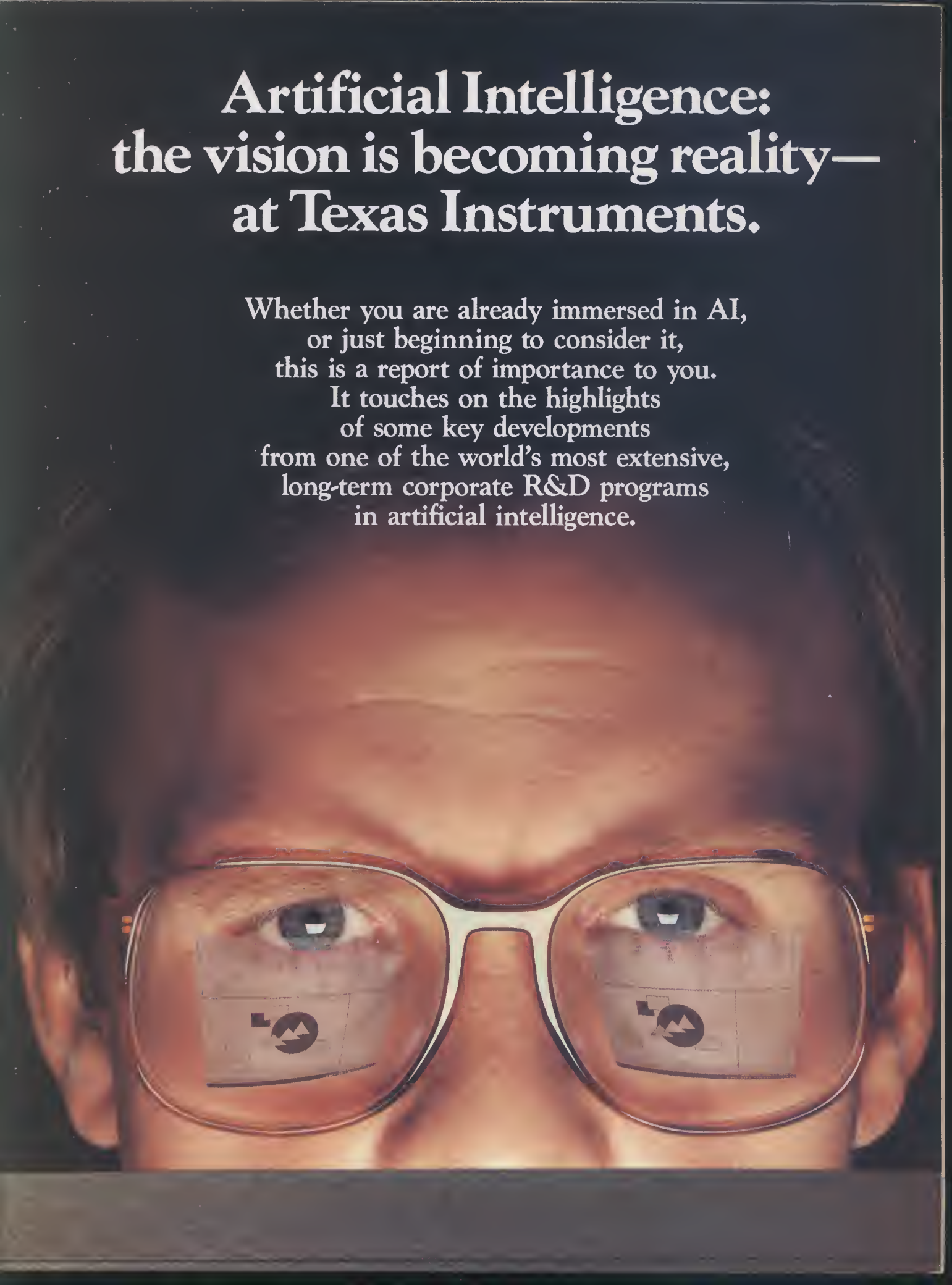
In the absence of a dramatic breakthrough in nonacoustic ASW, more sophisticated sonar systems and signal processing should improve detection capabilities by an order of magnitude within the next decade. But these advances in ASW surveillance will be largely offset by improved submarine technology, including quieter power plants, hulls made of nonmagnetic titanium or composites, anechoic coatings, and active countermeasures. For the foreseeable future, then, subs and sub hunters will probably continue to run neck and neck in their technological race.

Jonathan B. Tucker is a senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES** *on page 72.*

Artificial Intelligence: the vision is becoming reality— at Texas Instruments.

Whether you are already immersed in AI,
or just beginning to consider it,
this is a report of importance to you.
It touches on the highlights
of some key developments
from one of the world's most extensive,
long-term corporate R&D programs
in artificial intelligence.




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Previous
Read Background
Redraw
Reorder
Revert
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Define
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Kill
Kill or Save
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Modify
Restore
Save
Define
Explode
Insert
Restore
Save
Undefine
Pan Down
Pan Down Half
Pan Left
Pan Left Half
Pan Right
Pan Right Half
Pan Up
Pan Up Half
Set rewindow area
Show default window
Show entire picture
Zoom In
Zoom In Two
Zoom Out
Zoom Out Two
View and/or modify the parameters of an object
Key assignments: Meta-E
Cannot perform delete -- No objects selected
Cannot perform delete -- No objects selected
TEXAS INSTRUMENTS
EXPLORER

The next generation of computer technology is coming of age—at Texas Instruments.

Once again, Texas Instruments is pioneering important new technology which promises dramatic increases in human productivity. And, once again, TI brings technology within your reach through practical, problem-solving products at affordable prices.

Artificial intelligence is an emerging set of technologies whose goal is to enable computers to solve problems traditionally thought to require human intelligence or capabilities.

Key to these next generation systems is a significant new approach to computer programming known as symbolic processing. Conventional computer programs require precise sequences of mathematical steps carried out in a prestructured manner. Symbolic processing works with ideas and knowledge rather than numbers, analogous to the way humans reason with knowledge they possess.

Conventional computers experience many shortcomings in areas where symbolic processing systems have proven especially effective: dealing with complex problems, interpreting information, using "rules of thumb" gained by experience, and handling uncertain or incomplete information.

SYMBOLIC vs. ARITHMETIC	
Qualitative	Quantitative
Logical	Numerical
Inferential	Computational

People conceptualize ideas in symbolic terms rather than numbers. Symbolic processing computers manipulate information and knowledge in much the same way.

Symbolic processing, combined with other AI technologies—natural language, speech recognition and synthesis, computer vision—promises to open new dimensions in the way computers serve people. Using AI, computers can now be applied to the broader range of problem solving and decision making that people continually face in the real world.

At TI we're making AI work for you—now.

The transition from basic research to useful products is a commitment at Texas Instruments. We're concentrating not only on fundamental AI research, but on developing and marketing useful products that take full advantage of our experience. Today, TI has a number of products that are a direct result of this commitment.



The Explorer system represents an important advancement in providing exploratory programming and rapid prototyping capabilities for faster development of AI applications.

The TI Explorer™ system. Solving problems beyond the reach of traditional computing.

The Explorer system from Texas Instruments uses a new computer architecture especially designed for AI applications. It executes the language of artificial intelligence, LISP (List Processing). Programmer-friendly ease-of-use features promote rapid productivity for new users.

In contrast to conventional computers, which are designed for numerical data processing, the Explorer system is designed for the efficient processing of symbols and concepts, which represent real-world objects, their properties and relationships, and "chunks" of knowledge.

Until recently, symbolic processing systems were large, expensive computers that required special environments. This limited their use primarily to research laboratories. But, using its advanced semiconductor capability, TI has set a new standard for symbolic processing computers. The Explorer system's compact design, advanced user console, and powerful software packages now make it possible to move artificial intelligence solutions out of the laboratory and into the workplace.

For the company working on AI development, or for the organization just beginning to evaluate it, The Explorer system from Texas Instruments is a "must" consideration.

At TI we're using AI today ...for tomorrow.

TI has made an extensive commitment to the application of AI technology for in-house productivity and to solve customer problems. We began our R&D efforts in 1978 and are leading the way in bringing practical, cost-effective AI products to market.

As an established world leader in the research and development of symbolic processing computers, expert systems, and natural language and speech processing, TI is now utilizing the benefits of these efforts. We've discovered new ways to apply AI solutions to improve our own productivity—to speed and improve the development process for advanced VLSI semiconductors, to increase the productivity of automated production systems, to enhance the effectiveness of vital defense systems, to analyze seismic data more accurately for more effective oil exploration, and to develop software that provides better, more timely management information.

The results of these efforts, and our own experience, is bringing thoroughly tested AI products to the marketplace and making them available to an ever increasing number of disciplines.

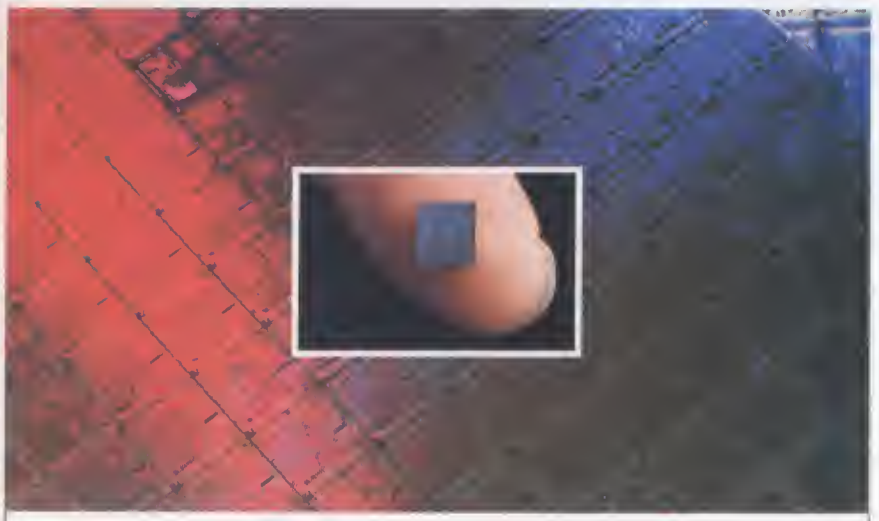
Expert systems, natural language processing, and speech recognition have been applied to fields ranging from genetic engineering to financial management to education. Symbolic processing computers such as Explorer are being used to perform tasks once thought to be solely the province of human experts: planning space missions, diagnosing machinery failures, designing control systems for chemical processing plants.

Texas Instruments dedication to research in artificial intelligence has made significant contributions to this exciting new field. As one of the world's largest technology companies, TI has the resources and commitment necessary to continue its leadership role in the development and production of reliable new products which capitalize on the results of artificial intelligence research.

The next generation of symbolic processing has already begun at TI.

One such program currently underway at Texas Instruments is the development of a LISP processor on a single chip. As part of the Strategic Computing Program of the Defense Advanced Research Projects Agency, this microprocessor is designed to provide up to 10 times the power of symbolic processors previously available.

This new chip will lead the way to many new commercial applications of artificial intelligence. When you link your AI development work to TI, you know you will stay at the leading edge of this fast developing technology—a potentially critical factor in competitive strategies for tomorrow.



A new single-chip LISP processor, being developed by Texas Instruments, will have 10 times the power of previously available symbolic processors.

TI's worldwide support and quality products help you make the most of AI technology.

To make artificial intelligence a practical reality takes more than product innovation. Texas Instruments already has a worldwide support system to provide technical assistance and follow-through. It's a total program of training, documentation, engineering support, and field service designed to provide you with the assistance needed to take maximum advantage of advanced AI technologies.

And for value, TI's exacting design and manufacturing standards enable us to deliver a higher quality product, a more reliable product, with greater functionality and at lower cost than would otherwise be possible.

Explore the promise of AI with TI.

- A proven track record for innovation in new technologies.
- An extensive, long-term R&D effort in artificial intelligence and the resources and commitment to sustain it.
- A leadership role in AI research applied to practical, affordable products—commercially available now—with new products under development.
- Consider TI's one-of-a-kind credentials in artificial intelligence. Whether you are just beginning to think about this new wave of computing technology or already have a program in place, Texas Instruments can help you lead the way.

For more information.

If you would like to know more about the exciting new developments in AI at TI, write to us at Texas Instruments, P.O. Box 809063, Dept. DEE02, Dallas, TX 75380-9063 and we'll send you additional information.

Bringing AI technology to personal computing.

Making technology affordable and accessible to more people is a prime mission at Texas Instruments. In putting AI research to practical use, TI has developed a number of new capabilities for personal computers that are making artificial intelligence applications available to everyone who needs them.

The Personal Consultant™—expert system development tools for personal computers.

The Personal Consultant software package from TI lets you develop and run expert systems on a TI Professional Computer or other personal computer.

Expert systems are computer programs designed to simulate the reasoning processes of human experts in a particular field—in effect, a computerized consultant. It asks a series of questions, and applies rules used by human experts to analyze the answers and make recommendations.

With Personal Consultant software, you can even ask for *help*, inquire *why* you were asked a particular question by the computer, or *how* the system reached its conclusion.

The economies offered by Personal Consultant make adaptation of this advanced technology practical for business and industry today, allowing the expansion of expert systems development and applications to a much greater degree than was affordable up to this time.

Arborist™—powerful decision-analysis software.

Arborist software illustrates the application of AI techniques to solve conventional problems. A combination of LISP processing language, multiple window displays, graphic representation of data, and plain English commands breaks through old barriers to make decision-tree problem solving techniques available to anyone who needs to make better and faster decisions.

Available as a direct result of TI research in artificial intelligence, this new software makes a versatile professional productivity tool easy-to-use and affordable on economical personal computers.

◀ *The Explorer computer system for high-performance symbolic processing.*

Natural language software—helping PCs use plain English.

A leader in the development of natural language interfaces, Texas Instruments developed NaturalLink™ software to allow people to communicate with computers in everyday English sentences, rather than in more traditional computer commands.

Invented in TI's Artificial Intelligence Research Laboratory, NaturalLink packages are available now to provide simplified access to many of today's most popular commercial PC software packages. These include word processing, spreadsheet, database, and graphics programs—programs that impact the majority of personal and business computing needs.

System developers may also build natural language interfaces for their own applications by using the TI NaturalLink Technology Package.

Computers that speak—and respond to the human voice.

Back in 1978, TI brought a major breakthrough in synthesized speech to the fingertips of children in practical, affordable, *talking* learning aids that spawned a whole new generation of electronic products.

With the emergence of personal computers, Texas Instruments has applied advanced speech technologies to PCs with the TI-Speech™ system. This innovation brings together our latest developments in both voice recognition and voice synthesis. The TI-Speech system permits users to verbally enter commands in the computer and provides sophisticated telephone management functions. It makes using a computer easier. And for some hands-busy applications, or for some handicapped individuals, it makes computerization possible.



The Business-Pro™ computer combines advanced personal computing power with capabilities for artificial intelligence applications.

Discover new dimensions in computing with the Explorer symbolic processing system.

From the company that pioneered the transistor radio, integrated circuit, electronic calculator, integrated-circuit computer, computer-on-a-chip, microprocessor, and synthetic speech.

Once again, Texas Instruments is pioneering an important new technology and bringing it within your reach through a practical, problem-solving product at an affordable price. The Explorer computer system will play a vital role both in extending the boundaries of knowledge and in delivering the products emerging from artificial intelligence research.

A closer look at the Explorer system.

The Explorer system is an advanced computer system designed for high-performance symbolic processing. The Explorer is ideally suited for the development and execution of software that employs artificial intelligence techniques to help solve complex application problems.

The LISP environment.

The system features one of the most productive software development environments available today. The software is based on Common LISP to promote portability and consistency of software applications among different LISP machines. The Explorer also provides high-level extensions to LISP, including Flavors—an object-oriented programming facility.

Unique software.

In addition to the standard LISP machine environment, Texas Instruments provides a number of unique software packages as a standard part of the system software. The Command Interface Toolkit provides standard interfaces to the system. The Suggestions Menu System helps novices rapidly learn the Explorer environment. The Glossary Utility offers online definitions of terms. These packages greatly reduce the time it takes a new user to become productive on the Explorer system.



Advanced hardware.

The Explorer hardware supports high-speed symbolic processing through a number of advanced architectural features. These include a tagged architecture for run-time data typing, bit-field hardware for manipulating complex data structures, hardware assisted memory management (garbage collection), and a 128M byte virtual address space. In addition, physical memory can be expanded to 16M bytes and disk storage can expand to 1120M bytes unformatted (896M bytes formatted).

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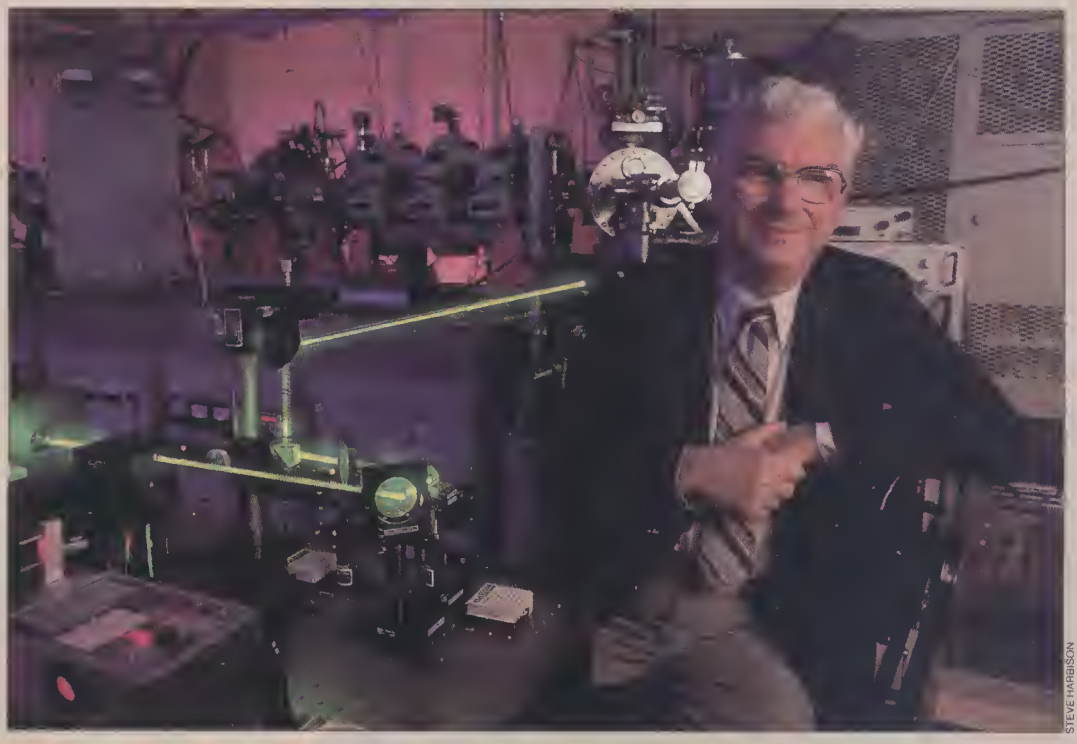
TEXAS INSTRUMENTS

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DEAZ040

NATIONAL LABS,



STEVE HARBISON

AT YOUR SERVICE

by Herb Brody

Forty years ago, World War II came to an end with the use of a terrifying piece of technology from new, top-secret government laboratories. Those facilities, at Oak Ridge, Tenn., Los Alamos, N.M., and a few other sites, have since grown into multipurpose "national labs" that perform wide-ranging R&D. While nuclear weapons still constitute much of their work, these labs are increasingly being enlisted to fight civilian battles. During the '70s the enemies were pollution and the energy shortage. The latest crusade: moving lab technology into the private sector to help restore the country's industrial competitiveness.

Closer collaboration with the private sector is helping to spawn new firms and shore up tired industries

The battle is being waged on several fronts. Patent policies, commonly cited as a major hindrance to commercialization of government technology, are loosening up. The labs now welcome private sponsorship for proprietary product development. A new exchange program lets companies send their technical people to work shoulder to shoulder with their colleagues at national labs, while the government picks up much of the tab. The labs are also being enlisted to apply their resources to aid struggling basic industries, like steel.

Until recently, the government took the position that the fruits of publicly funded R&D should be available equally to everyone. Thus any patent awarded for work at the labs became government property; the government then offered licenses to all interested U.S. companies for a small fee.

But these nonexclusive licenses discourage commercialization. Because the technology produced by the labs is unrefined—typically 90% of product development remains to be done when

Hal Schmidt (above) formed Atom Sciences with patents and consulting from Oak Ridge. "There aren't a lot of barriers now," he says.



STEVE HARBISON

Martin Marietta's Carpenter, shown with a corrosion-resistant hip replacement, is leading Oak Ridge toward greater commercial relevance.

the government ceases its work—it makes little sense for a company to embark on an expensive, risky product development effort using technology freely available to its competitors. Firms are "reluctant to invest the millions of dollars required to fine-tune inventions without the guarantee that a competitor could be precluded from receiving its own government license," explains Jon Soderstrom, director of of research and technology applications at Oak Ridge National Laboratory.

As a result, "for decades, what we did here didn't matter very much" to the industrial world, says William Carpenter, vice-president for technology applications at Martin Marietta Energy Systems, which operates Oak Ridge for the Department of Energy (DOE). Technology that's available freely to everyone is "of value to no one," he contends.

A wave of patent-policy changes began with the passage of the Bayh-Dole Act of 1980. This act allows small businesses or nonprofit organizations to retain title to inventions conceived during government-sponsored R&D. An amendment to the act, signed last fall, broadens the government's waiver of patent ownership. The new law states that nonprofit institutions (such as universities) that operate government labs under contract can retain title to inventions coming out of these labs. In addition, former Energy Secretary Donald Hodel ordered last February that the patent waiver be extended to cover large, for-profit companies like Martin Marietta, but as of this writing the rule had not taken effect.

The attention recently given to patent policy symbolizes the new concern in Congress and the administration over getting our money's worth out of the national labs. Such concern first became prominent in the Stevenson-Wydler Technology Innovation Act of 1980. The law declares technology transfer to be an official mission of the labs and requires that each lab spend 0.5% of its budget on moving the results of its R&D into industry.

Perhaps more galvanizing than the Stevenson-Wydler Act, however, was the sharply critical 1983 report on the labs by a presidential commission. The panel, chaired by Hewlett-Packard cofounder David Packard, urged greatly increased interaction between government labs and industry in order to make the labs "more responsive to national needs." It accused the labs of working without clear purpose, and

therefore contributing insufficiently to the national good. The Packard panel recommended that the size of each lab be "allowed to increase or decrease (to zero if necessary) depending on mission requirements," adding that "preservation of the laboratory is *not* a mission."

A direct outgrowth of the report, and a striking example of how the labs can be channeled to industry's service, is the "steel initiative." The plan is to use the potent scientific and engineering talents of the national labs to perform basic research that the ailing steel companies cannot fund themselves.

Because of financial hardships, steel company R&D is "typically geared for results in six months to a year," explains John Roberts, associate director of Argonne National Laboratory (Argonne, Ill.), which will do much of the work. The companies recognize the magnitude of their plight. The steel initiative will look 10–15 years into the future, says Roberts; it is to be a collaborative project in which steel companies like U.S. Steel, Bethlehem, National, Armco, and LTV will send their scientists to work in teams with the lab scientists to solve problems jointly agreed upon. "Incremental improvements aren't enough" to restore the industry's badly eroded competitive position, says Reginald Dietz, vice-president for research at National Steel (Weirton, W.V.). "We're going after 'leapfrog' technology that will put us a couple of steps ahead." The labs will work not on proprietary projects but on generic technologies that the entire industry should share.

One thrust of the program will be to find new ways to convert iron ore into liquid metal, bypassing the expensive coking ovens and blast furnaces now used. Another focus will be on casting the liquid metal into pieces close to the dimensions of the final product. One possibility is to use powerful, precisely shaped magnetic fields to confine the molten metal so it can be cast into thin sheets, obviating the need for strip mills to flatten thick billets. The technology loosely resembles that being developed to confine hot hydrogen gas for controlled nuclear fusion. Oak Ridge, which has a long-standing program in fusion, will contribute its magnet expertise to the problem of casting steel.

Shortly after the steel initiative was organized, George A. Keyworth II, Reagan's science advisor, asked the national labs to identify other industries that might benefit from a similar effort. The result was a proposed project for applied research on off-road machinery. In March, Argonne met with several manufacturers to determine which technical issues were appropriate for cooperative action. The resulting list includes advanced engines, electronic controls, and continuously variable transmissions. The lab hopes to begin work in fiscal 1987.

Unlike the steel initiative, the off-road equipment project will aim to develop specific products rather than basic technology. To make this work, the labs will have the liberty—unusual for the government—to keep proprietary secrets. "We won't have to tell Deere what we're doing with Caterpillar," says Argonne's director of technology transfer, Brian Frost.

Increasingly, the national labs are becoming spawning grounds for technology-based start-ups. From Oak Ridge's inception during World War II until 1980, about 20 companies started up with technology developed at the lab, according to technology transfer manager Donald Jared; in the following four years, he says, there were more than 30 such spinoffs.



STEVE HARBISON

A glass devised to encapsulate nuclear waste may be adapted for lens making by an Oak Ridge start-up.

Some of these new companies are formed under arrangements that would have been unheard of a short time ago. Perhaps the most dramatic example comes from Los Alamos. Scientists there developed a way to identify viruses and bacteria in minutes, rather than the days or weeks needed with existing methods. A laser illuminates the sample with a beam that alternates between two kinds of polarization, and a detector senses the difference in how one polarization is scattered relative to the other. This difference, it turns out, correlates with certain features of the specimen's DNA molecule.

The procedure was invented at Los Alamos in a project funded by the National Institutes of Health. NIH had no interest in commercialization, though, and ceased its support while the device was still far from market readiness. The lab began looking for companies to acquire the technology. When David Silver, a Chicago venture capitalist, came to Los Alamos in 1983 in search of technologies ripe for commercial exploitation, the rapid analyzer stood out.

Silver raised $8.5 million through an R&D limited partnership with Prudential-Bache Securities (New York) and gave half the money to the lab to develop a commercial prototype. The partnership (a tax shelter to encourage investment in technology) acquired full ownership of the technology and then granted an exclusive license to a new company, Mesa Diagnostics (Los Alamos). Mesa is wholly owned by Silver's venture capital firm, the Santa Fe Private Equity Fund.

It is a curious reversal of conventional practice, with the big government lab working for the small company instead of the other way around. The partnership pays the lab for use of its staff during regular hours and hires lab scientists as consultants after hours. "It's cheaper than hiring our own staff," says John Lonergan, Mesa's chief financial officer and vice-president for marketing.

It took two years to put the radical deal together, according to Eugene Stark, the lab's industrial liaison officer. The main hang-up was the patent. DOE had to waive its title to the University of California (which operates the lab), and then the university had to waive its title to Silver's partnership. Eventually, 11 contracts were needed to cement the agreement, according to Silver.

While the Mesa deal is unusual in its magnitude, it is one of a growing number of cases in which a small company is launched with national lab technology that would not have been available under old policies. For example, Kelsius (San Carlos, Cal.) bought into the sensor business with an exclusive license to the technology of remote fiber fluorimetry developed at Lawrence Livermore National Lab.

The sensor consists of an optical fiber whose tip is coated with a material that glows in the presence of certain other compounds. The light, which varies in brightness with the concentration of the substance being sensed, travels down the fiber to a detector. Kelsius plans to use the technique in a blood-gas monitor; a fiber will be inserted into the bloodstream, and the fluorescence will indicate the levels of oxygen, carbon dioxide, and pH, says president Jay Schwalde.

Radtech (Albuquerque), a Los Alamos spinoff, is developing systems that use radio-frequency electrical current to heat and thus reshape the cornea, correcting visual defects. The company aims for a one-hour outpatient procedure that is simpler, cheaper, and less risky than the present surgical alternatives.

Consulting by lab staff is another important way to get know-how into industry. In the past, the national labs had discouraged—or prohibited—scientists from marketing the expertise they gained from government work. This restriction made it difficult, if not impossible, for would-be entrepreneurs to use laboratory scientists' skills. But more liberal policies have permitted the start-up of firms like Atom Sciences (Oak Ridge). The company aims to commercialize an ultrasensitive measurement system that uses precisely tuned lasers to ionize and then count the atoms in gaseous or solid samples. As little as 0.1 part per billion is detectable, and the system works on any element for which proper laser wavelengths are available, says cofounder Hal Schmidt.

The laser technique was invented several years ago by Oak Ridge scientist Samuel Hurst. While remaining on the lab staff, Hurst has been permitted to become a cofounder and vice-president of Atom Sciences, as well as a consultant to the firm—all capacities that had been off limits for lab staff. "There aren't a lot of barriers now" to such involvement, says Schmidt, recalling the stiff opposition he met in 1960 when he and colleagues started Ortec, a maker of nuclear particle detectors. Hurst concurs: "There is no longer a perception that the entrepreneurial process is a conflict of interest."

The labs are also more willing now to grant leaves of absence. Amtech, for example, was started locally by five scientists on two-year leaves from the Los Alamos lab. The company has acquired a remote identification-tag technology that the lab had developed for the Department of Agriculture. The tags are read from a distance by microwaves; an electronic circuit in the tag alters the reflected microwave beam in an easily detected way. DOA's goal was a label for diseased cattle that would keep them out of the slaughterhouse. But the principal application Amtech sees, according to R&D vice-president Jerry Landt, is keeping tabs on the contents of railroad cars—for example, making sure that all the cars in a single-commodity "unit train" stay together.

Although each national lab is changing, none has pursued technology transfer as aggressively over the past year as Oak Ridge. The sprawling facility at the edge of the Smoky Mountains in eastern Tennessee is setting the pace for the others in the national lab archipelago. This leadership dates from April 1984, when the contract for running Oak Ridge went from Union Carbide to Martin Marietta; the aerospace company beat out competitors Rockwell and

The business community is gradually becoming aware of the national laboratories' resources







BRIAN WALSKI



DAVE VAN DEVEER

Sandia's Stromberg (left) says companies now "realize it's worth bothering" to work with national labs. The ailing steel industry looks to the future by collaborating with the labs in developing radical steel-making methods, says National Steel's Dietz (above). Venture capitalist Silver (top) struck an unusual deal: His new company hired Los Alamos to develop a marketable product.

Westinghouse with a bid that heavily emphasized industrial participation and strengthening the local economy.

"We proposed doing business in a new and different way," says Carpenter at Martin Marietta Energy Systems, the subsidiary formed to handle the lab contract. For example, Martin Marietta has asked DOE for ownership of all patents the company deems to be of commercial potential—an "advance waiver of title" that would let Martin Marietta act with autonomy. As owner of the technologies devised at Oak Ridge, the company would grant other firms exclusive licenses to bring the inventions to market. Although DOE has not yet granted this waiver, Martin Marietta has begun negotiating license agreements with other companies in anticipation. "When the word comes, we'll be ready to go," says Carpenter. "We expect to have some home runs."

Martin Marietta also strongly encourages the Oak Ridge technical staff to serve as consultants—to "get our smarts out into the private sector," as Carpenter puts it. In contrast, Union Carbide had put a ceiling on how much a lab scientist was allowed to earn on the outside; some other national labs, particularly Sandia, continue to enforce tight restrictions on off-hours consulting.

In another shift, Oak Ridge now welcomes private sponsorship of proprietary R&D. A number of companies, including Cabot (Boston), Homogeneous Metals (Clayville, N.Y.), and Universal Cyclops (Bridgeville, Pa.), are paying the lab to develop a new class of alloys with a unique property. Unlike most metals, which get weaker as they heat up, these "ordered intermetallic alloys," such as nickel aluminides, get stronger. This property is especially useful for engines, which operate most efficiently at higher temperatures. Present nickel aluminides are barred from structural use by their brittleness. Oak Ridge is working on ways to increase ductility and has obtained dramatic improvements by adding small amounts of other materials, such as boron.

Martin Marietta has also made a significant commitment to accelerating the growth of the local economy, having allocated 10% of its annual contract fee (for running the lab) to launching new companies. (The fee ranges from $5 million to $20 million, depending on Martin Marietta's performance.) In addition, the company has promised to build a 290-acre industrial park near the lab. The first tenant will be the Tennessee Innovation Center, a new subsidiary that will invest in and "incubate" high tech start-ups. The center is co-owned by Tran Tech Systems (Salt Lake City), which runs the similar Utah Innovation Center.

The Tennessee Innovation Center, a for-profit organization, identifies promising technologies at the national lab and "does everything necessary to make them commercially successful," says vice-president Melvin E. Koons. The center makes equity investments, typically of $50,000–$150,000, for start-ups that satisfy several key requirements—a product or service on the cutting edge of technology, potential for generating revenues of $7–10 million in 5–8 years, and a promise to locate in Oak Ridge.

The center tries to find commercial uses for inventions geared to specific government purposes. For example, a new lead-iron phosphate glass was de-





Los Alamos scientists Charles Gregg (left) and Gary Salzman are building a commercial prototype of their rapid-diagnosis system with private funding. Aerial view shows the lab's main technical area.

FRED RICK

for encapsulating nuclear waste. It turns out that the glass has some unusual properties that allow it to be poured as a liquid into precisely shaped molds. An exciting possibility is the direct casting of lenses, eliminating much of the expensive grinding and polishing needed for ordinary glass. The center hopes to invest in a start-up to explore further the material's commercial potential.

Despite all these efforts to make the national laboratories more relevant to industry, the labs are still largely cut off from industry scientists. DOE is seeking to remedy this isolation with a new lab/industry exchange program. Technical staff from interested companies—U.S. or foreign—will be able to spend a year working at a national lab, with the government paying part of their salaries and expenses. The program's $600,000 budget for this fiscal year should pay for 20–30 scientists, says Richard Stephens, director of university and industry programs in DOE's energy research office.

But whose agenda will the visiting scientist follow—the company's or the lab's? Stephens emphasizes that work should benefit both. "We don't want simply to augment a company's R&D," he says. "There should be a mutual interest."

The new industrial orientation of the national labs is not without its critics. The fostering of spinoff companies, for example, is seen by some as a potential distraction. Examples like Mesa Diagnostics at Los Alamos could tempt scientists to "think more of possible commercialization than of the value of their work to the government," says Everet Beckner, vice-president for energy programs at Sandia Corp., the AT&T subsidiary that runs Sandia National Labs (Albuquerque).

For instance, an entrepreneurially minded scientist may devote less attention to work on classified projects because there is less potential for commercial spinoff, says Frank Huband, head of technology policy at the National Science Foundation. And he warns that a "Russian farm" mentality could arise at the labs. In the Soviet Union, farmers are permitted to work a small private lot for profit; but a frequent result is that the farmers focus their energy and ingenuity on making the private lot more productive, while giving only minimal attention to the collective land.

In addition, some argue that spinning off new companies is an inefficient way for a lab to help the economy. "People hear that small companies are the biggest job producers, which is true, and they twist that into the false notion that *start-ups* are the biggest job producers," says Robert P. Stromberg, manager of technology transfer at Sandia. Most new companies don't survive long enough to provide many jobs, he says. Not surprisingly, then, much of Sandia's technology transfer involves established firms, such as large oil and gas companies.

One effective way to exploit national lab R&D arose informally, well before the current programs were conceived, with the Federal Laboratory Consortium (FLC). Over 100 labs, including the eight national labs, belong to what chairman Eugene Stark of Los Alamos calls an "organized old-boy network." A company in need of technical information or assistance contacts one of four regional coordinators, who check to see whether any federal lab is working on the topic. Legislation now pending would make FLC an officially recognized (and funded) organization, probably as an arm of NSF. Such a move would be a boon to technology transfer because "the FLC guys won't have to spend all their time begging for money," says one congressional staffer.

Thanks to the new programs and FLC's persistent efforts, industry is catching on that the national labs have turned a new leaf. "Companies are realizing that it's worth bothering" to do business with the labs, says Sandia's Stromberg. For many years, says Stark at Los Alamos, the labs turned down more requests for visits from the Japanese than they received from U.S. companies. That's no longer true. And "the companies involved now," he says, "are skimming the cream."

Herb Brody is a senior editor of HIGH TECHNOLOGY.

For further information see **RESOURCES** *on page 72.*

Scanning Tunneling Microscopy

IBM

To: Robin
From: Roger
Subject: IBM Technology

I've been reviewing some of our past and present technological achievements, and it occurred to me that the scientific, engineering, and academic communities might like to know more about them. Will you select a topic from the following list or suggest another one? Thanks.

Vacuum tube digital multiplier
IBM 603/604 calculators
Selective Sequence Electronic Calculator (SSEC)
Tape drive vacuum column
Naval Ordnance Research Calculator (NORC)
Input/output channel
IBM 608 transistor calculator
FORTRAN
RAMAC and disks
First automated transistor production
Chain and train printers
Input/Output Control System (IOCS)
STRETCH computer
"Selectric" typewriter
SABRE airline reservation system
Removable disk pack
Virtual machine concept
Hypertape
System/360 compatible family
Operating System/360
Solid Logic Technology
System/360 Model 67/Time-Sharing System
One-transistor memory cell
Cache memory
Relational data base
First all-monolithic main memory
Thin-film recording head
Floppy disk
Tape group code recording
Systems Network Architecture
Federal cryptographic standard
Laser/electrophotographic printer
First 64K-bit chip mass production
First E-beam direct-write chip production
Thermal Conduction Module
288K-bit memory chip
Robotic control language
Masterslice and the Engineering Design System

Roger -
IBM's researchers have developed a powerful new technique for studying surfaces at the atomic level: let's tell this story!
Robin



Figure 1. *This three-dimensional representation of a silicon surface was obtained by scanning tunneling microscopy, developed by IBM. The individual hills or bumps indicate actual atoms separated by as little as six angstroms. (One angstrom is one ten-billionth of a meter.)*



Figure 2. *IBM's new microscopy technique makes use of a phenomenon called vacuum tunneling, which involves the passage, or tunneling, of electrons between two conducting or semiconducting solids that are narrowly separated by a vacuum. Tunneling occurs because electrons have wavelike properties as well as particle properties. This means, according to quantum theory, that electrons appear as electron clouds that spill out slightly beyond the surfaces of the solids in which they originate. As a result, there is a finite probability that electrons will tunnel through the vacuum.*

Miniaturization is the driving force behind the computer revolution. As computer chips continue to evolve, their structural details are becoming so small that it is vital to understand them at the atomic level.

Recently, IBM researchers have succeeded in examining structures at the atomic level by developing an absolutely new kind of microscopy technique—scanning tunneling microscopy, or STM. Specifically, they have produced three-dimensional images of the surface topography of solids that show vertical position differences as small as 0.1 angstroms (one angstrom is one ten-billionth of a meter) and horizontal position differences as small as six angstroms. Such simultaneous resolution is unprecedented.

The new microscopy technique makes use of a quantum-mechanical phenomenon called vacuum tunneling, which involves the passage, or tunneling, of electrons between two conducting or semiconducting solids that are narrowly separated by an insulator or a vacuum.



Figure 3. *The principle of the scanning tunneling microscope is quite simple. As a probe tip is scanned across a surface's microscopic hills and valleys, its vertical position is adjusted to maintain a constant tip-to-surface distance (by keeping tunnel current constant). The probe consequently follows the surface contour as it moves, so that monitoring its vertical position can be used to yield a two-dimensional representation of the surface contour for each scan. The full three-dimensional image is obtained by assembling an entire sequence of scans.*

Scanning Tunneling Microscopy



Figure 4. *The scanning tunneling microscope is contained inside this chamber. The electronics (background) collect and process the measurements and then display the results on a screen or plotter. An absolute necessity for making measurements is a vibration-free suspension, which also had to be specially developed by the IBM researchers.*

Tunneling through solid insulating barriers was first demonstrated in 1957; it was only early in 1982 that controlled vacuum tunneling was demonstrated by IBM in an experimental configuration suitable for microscopy.

In principle, the scanning tunneling microscope takes advantage of the strong dependence of the tunnel current on the separation between two solids. One solid has its surface under investigation; the other, a metal tip, is a probe electrode. As the probe moves laterally across the surface (while separated from it by about ten angstroms), the tunnel current will vary in accordance with changes in the tip-to-surface distance. The tunnel-current variation in effect is a measure of the surface topography.

In practice, the vertical position of the probe is changed to keep the tunnel current, and thus the tip-to-surface distance, constant for all points. In that way, monitoring the position of the tip while scanning yields a topographic picture of the surface. The technique is so sensitive that a change in tip-to-surface distance by the diameter of a single atom produces a tunnel-current change by a factor of 1,000.

By providing a more detailed view of surface structures, STM has already significantly advanced the understanding of important materials such as silicon. However, STM is more than a surface structural tool with atomic resolution; it also images surface parameters (such as composition and oxidation state) and can determine electronic properties. This opens fascinating possibilities in many areas of science and technology.

STM can be performed at ambient pressure and can see surfaces covered by nonconducting liquids. The ability to operate under such conditions makes STM attractive in many different fields, from engineering to biology.

Scientists at the IBM Zurich Research Laboratory developed the world's first scanning tunneling microscope. Their contributions are only part of IBM's continuing commitment to research, development, and engineering.

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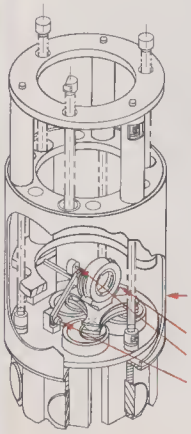


Figure 5. *Photograph and illustration of the scanning tunneling microscope. Note that the microscope is lowered into the chamber (shown in Figure 4) when in use.*

For free additional information on STM, please write:
IBM Corporation, Dept. 1003,
P.O. Box 5089, Clifton, NJ 07015

PREVENTING MIDAIR COLLISIONS

Airborne threat-alert systems can monitor nearby planes and prescribe evasive action



Passengers flying on a Piedmont Airlines Boeing 727 will soon enjoy added protection against possible midair collision, thanks to a new threat-alert/collision avoidance system (T/CAS) that surrounds the plane with an invisible "radar shield." Piedmont is running the first commercial T/CAS tests, and by the end of this decade many of the nation's airliners are likely to be equipped with such systems. If successful, they will provide an ever-vigilant backup for ground-based radars, computers, and human traffic controllers.

by Ken Julian

Once every second, T/CAS will make a complete survey of other aircraft within a range of about 15 miles, measuring their altitudes, distance separations, closing rates, and approximate bearings. If any of these planes pose a threat, T/CAS will alert the flight crew and display the approximate location and relative altitude of the encroaching aircraft. During good visibility conditions the flight crew will monitor the situation visually. In poor visibility, or if the situation worsens, T/CAS will automatically determine whether its aircraft should climb or descend, at a moderate 1500 feet per minute, to avoid a possible collision. The appropriate maneuver will be displayed in time for the flight crew to react and for the aircraft to achieve a safe vertical separation of at least a few hundred feet.

T/CAS will add security to an aircraft monitoring system that has proved very effective in recent years. The last midair collision involving a commercial airliner in the U.S. occurred on September 25, 1978, when a Pacific Southwest Airlines 727, descending to land in San Diego in broad daylight and good visibility conditions, collided with a small plane (a Cessna-172). Since that tragic accident, which killed 189 persons, including seven on the ground, the Federal Aviation Administration's ground-based air traffic control system has prevented a recurrence.

Despite this reassuring record, near misses between planes are not uncommon. And the dramatic photo of the mortally wounded PSA airliner plunging to earth continues to haunt those responsible for providing safe separations between the growing numbers of aircraft. If two jumbo jets collided over a large city, for example, the death toll could approach 1000. Thus the incentive for T/CAS.

Slow evolution. The present T/CAS evolved from a program initiated in 1955 by the Air Transport Association of America (ATA) on behalf of its member airlines. In those days, the nation did not have an extensive network of ground radars to provide aircraft sur-



veillance or large computers to detect potential conflicts and alert human controllers. In good visibility, safe separation of aircraft depended almost entirely on the vigilance of flight crews. In poor visibility, traffic controllers on the ground attempted to maintain safe separations, relying solely on radio reports from pilots who estimated their positions using inaccurate and unreliable ground navigation aids.

The need for an effective airborne collision avoidance system was driven home less than a year after ATA challenged the aviation electronics (avionics) industry to invent such a device. On June 30, 1956, two large airliners collided in broad daylight and good visibility conditions near the Grand Canyon, killing 128 people. Spurred by this tragedy, several leading avionics companies promptly proposed collision avoidance systems. The airlines selected Collins Radio (Cedar Rapids, Iowa), later acquired by Rockwell International, to develop its system.

Collins proposed enclosing an aircraft in a "cocoon" of radar beams that would strike nearby planes and be reflected back to a receiver. The main attraction of this scheme was that it was "noncooperative"; it would protect an aircraft whether or not other planes in the vicinity were similarly equipped. But within a few months, Collins reached an impasse: Its radar wasn't accurate enough to measure precisely the bearing or change of bearing of another plane. Thus the system had to issue an alarm each time a plane entered the "cocoon." The problem of detecting potential collisions without generating excessive numbers of false alarms proved far more difficult than anticipated, and the company terminated its contracts without charge.

During the next decade, many avionics firms came up with alternative ideas—such as broadening the use of the airborne weather radar already carried by airliners to spot severe thunderstorms—but all had significant shortcomings. It became clear that the crucial problem was not one of detecting the proximity of other aircraft but one of accurately assessing whether there was a real collision threat.

This problem seemed insurmountable, so in the mid-1960s the airlines abandoned hope of obtaining a satisfactory noncooperative system and turned instead to a cooperative type. With such a system, each aircraft would be equipped with a special transmitter and receiver. The transmitter would periodically send out interrogations that asked, in effect, "Is anybody in my vicinity? If so, what is your barometric altitude?" The companion receiver would listen not only for replies but also for interrogations from other aircraft (to which its own transmitter would reply).

By measuring the fraction of a second required for one aircraft to receive a reply from another, the distance between the two could be determined. Similarly, comparing barometric altitudes could establish whether there was a safe vertical separation. And by measuring the rate at which both distance and altitude separations were changing, the cooperative system could assess whether there was risk of collision. McDonnell Douglas (St. Louis), which had developed a system after two of its own fighter aircraft collided in midair, and Honeywell (Minneapolis) both demonstrated the feasibility of such an approach, although neither put their systems into general production.

Why not? Because cooperative systems offered no protection against unequipped aircraft. The systems might have proved too expensive for owners of small planes like the Cessna involved in the San Diego tragedy. And they would have been too bulky for use on high-speed military jet fighters.

Ground radar matures. Fortunately, by the early 1970s the risk of midair collisions had diminished significantly because of major improvements in the FAA's ground-based air traffic control system. These improvements included the introduction of a new type of radar and high-speed digital computers. Previously the FAA had depended on conventional radar, which bounces pulses of microwave energy off the fuselage of an aircraft. The plane's distance is indicated by the return time; its azimuth (horizontal direction), by the position of the rotating radar antenna when the pulses are received. But such "primary" radar provided no in-

ILLUSTRATION BY MARK E. ALSOP

ALSOP



Reenacting a San Diego air tragedy, a T/CAS system developed by MIT's Lincoln Laboratory displays a commercial plane (center) and two encroaching planes (yellow triangles). The transponder on one of the latter planes has an altitude-reporting feature (−12 indicates it is 1200 feet below the T/CAS plane); the second plane's transponder lacks this feature, as indicated by the question marks. When one plane exceeds set danger limits, its color changes from yellow to purple and the top warning light switches from yellow to red. At this point, an audio resolution advisory instructs the pilot to climb or descend.

formation on altitude. Lacking this vital third dimension, a ground controller was seriously handicapped. For example, two nearly coincident blips on a radar display could indicate two planes that are either in imminent peril of collision or safely separated by more than the required altitude—1000 vertical feet below 29,000 feet, 2000 vertical feet above.

By the early 1970s, a more sophisticated, "secondary" radar came into use. This type could determine the barometric altitude and identity of each aircraft, provided the plane was equipped with a radar transponder—a device roughly the size of a home stereo receiver. This same transponder would later be incorporated in the present T/CAS system.

A ground radar illuminates a plane with a brief pulse-coded interrogation that asks, in effect, "What is your altitude?" and "What is your identity code number?" The plane's transponder promptly replies. The identity code number is assigned to the flight and entered into its transponder just before departure; it is also entered into the FAA's traffic control computers.

Whenever a ground radar receives a transponder reply, the computer generates a "tag" that appears next to the blip to identify it and to show the plane's barometric altitude. Because the computer knows the position of each transponder-equipped aircraft in three dimensions, it can continuously search for collision threats and alert the human controller if one develops.

In the early 1970s, the FAA made altitude-reporting transponders mandatory for all aircraft flying above 12,500 feet or operating at any altitude in the terminal areas of about two dozen major cities. All U.S. military aircraft are equipped with similar transponders to enable air defense radars to distinguish them from potential enemy aircraft. As a result, all large high-speed civil and military aircraft carry transponders, and many small-plane owners have opted to install them as well (the Cessna-172 involved in the San Diego crash carried such a device).

Cooperative rebirth. By the mid-1970s, the proliferation of radar transponders raised the prospect that they might form the cornerstone of an effective cooperative-type airborne collision avoidance system. One scheme—which had its genesis in some earlier efforts by George B. Litchford, an inventive consulting engineer—took form at Mitre Corp. (McLean, Va.). The idea was to equip commercial planes, large business jets, and military aircraft with a miniaturized version of the secondary ground-based radar and its associated digital computer. Each aircraft would periodically send out interrogations eliciting altitude and identity data from every transponder-equipped plane in the vicinity.

One challenge was to squeeze the functional capabilities of a large ground radar and digital computer into a package about the size of a home video recorder and weighing less than 50 pounds. But the most difficult problem was one already associated with ground-based secondary radar. If two or more aircraft are at roughly the same distance and direction from a ground radar, even though safely separated in altitude, their pulse-coded replies will reach the ground radar at about the same time. As a result, the reply pulses from one aircraft may be interleaved with those from another, confusing the ground computer.

This problem, known as garble, is analogous to trying to eavesdrop on a conversation at a loud cocktail party. The problem becomes even more acute if the aircraft are being illuminated by several ground radars at once. In such instances, each ground computer must try to distinguish which replies are to its own radar and which are to another radar. To reduce this garbling to acceptable levels, the FAA has introduced better ground radar antennas and more sophisticated data processing.

But if many aircraft were outfitted with a collision avoidance system and each were sending out interrogations to which every other aircraft transponder would reply, the resulting Babel of pulses would be impossible to decode.

Mitre scientists came up with a novel technique—called whisper-shout—for easing this problem. To limit the number of transponder replies in the air at any instant, an airborne collision avoidance system first transmits its interro-



CHRISTOPHER CUNNINGHAM

gation at a very low power level (whisper) that is "heard" and replied to only by nearby aircraft. This is followed by a slightly higher-power interrogation that is received by slightly more distant aircraft but ignored by the closer transponders, which have already replied. This is followed by a slightly higher-power interrogation, and so on. Whisper-shout was refined at MIT's Lincoln Laboratory (Bedford, Mass.).

A complementary technique to further reduce garble was devised by Textron/Bell Aerospace's Dalmo Victor division (Belmont, Cal.), which manufactures the T/CAS system to be used in the upcoming Piedmont evaluation. Dalmo Victor drew from its work in designing military aircraft radar warning receivers that detect and analyze enemy radar signals to determine their function and location. A small antenna on top of the fuselage cuts the garble problem 75% by transmitting whisper-shout interrogations in 90°-wide azimuth sectors rather than in all directions at once.

The same antenna also receives transponder replies and can determine the approximate bearing of each responding aircraft. This enables the system to provide the flight crew with a color cathode-ray tube display showing the approximate bearing, distance, and altitude separation of each potential threat. The system also shows severe turbulence detected by the aircraft's weather radar.

In operation, the system transmits 24 whisper-shout levels of interrogation in the forward quadrant, followed by a slightly smaller number to either side, then to the rear. This cycle is repeated once a second. Each interrogation is coded to instruct a transponder to ignore the "louder" interrogations that immediately follow. After each interrogation, the system listens for about 250 microseconds—long enough to hear replies from other aircraft within 15 miles, but not long enough to pick up replies from more distant aircraft that currently pose no threat. Extensive simulation and flight tests have shown that these and other degarbling techniques should enable Dalmo Victor's T/CAS to operate in terminal areas with traffic densities of more than 90 aircraft within a radius of 10 nautical miles. This is the highest density projected for anywhere in the U.S. by the end of this decade.

By then, the interference problem should begin to ease as the FAA introduces an improved type of secondary radar system, called Mode-S, which can selectively interrogate an individual aircraft's transponder by means of its identity code, making the whisper-shout technique unnecessary. Mode-S will permit the use of more than a million different identity codes, so that a code can be permanently assigned to each aircraft.

In order to identify a threat, the collision avoidance system first decodes a reply to determine the altitude of the other aircraft. If both aircraft are at or near the same altitude, the system then calculates the distance to the "intruder." After data have been acquired for several seconds, the T/CAS computer can determine whether the vertical and lateral separations are decreasing, indicating a potential conflict, or whether one or both are increasing, indicating that the other aircraft poses no danger. The computer can keep track of up to a dozen potential threats simultaneously.

Evasive action. Of course, a collision avoidance system must do more than simply identify threats. It must also advise the pilot when to perform an evasive maneuver. T/CAS can't predict with certainty whether an intruder is on a collision course. But through tests and simulations, system designers have determined the amount of time required for a flight crew to respond to an escape maneuver command and for the aircraft to achieve a safe separation.

For each potential threat, T/CAS divides the separation distance by the closing rate to calculate "tau"—the time remaining in seconds until minimum separation or collision will occur. T/CAS alarm thresholds above 18,000 feet have been set according to a worst-case scenario: two 600-mph jetliners in a head-on encounter. When the tau-value reaches 45 seconds, the system issues a "traffic advisory" by means of an audible alert. The threat aircraft, previously shown in green on the color display, now changes to amber. The system displays the intruder's approximate bearing and relative altitude to give the flight crew a chance to spot the other plane and assess whether corrective action will be needed.

If the situation deteriorates to the point where tau reaches 30 seconds, T/CAS will issue a "resolution advisory" accompanied by another alarm. The symbol for the threat aircraft now turns red and an arrow tells the crew to climb, descend, or level off. The resulting 1500-foot-per-minute escape maneuver should be barely perceptible to passengers. But it is sufficient to provide a safe vertical separation even if the other aircraft is not equipped with T/CAS and takes no action.

FAA adopts a laissez-faire attitude—for now

The present FAA policy toward airborne threat-alert/collision avoidance systems (T/CAS) is that their use aboard airliners as well as business and private aircraft should be optional, because the system is viewed as a backup in case of a failure in the FAA's extensive ground-based air traffic control system. But that policy could change overnight if there were a midair collision involving two large airliners with a heavy loss of life.

A different type of disaster prompted the agency's sudden about-face on another airborne safety device just over a decade ago. In the early 1970s, Sundstrand Avionic Systems (Redmont, Wash.) had developed an airborne system that could alert a flight crew if its aircraft was dangerously close to the ground, but the FAA chose not to make it mandatory. Then, on December 1, 1974, a TWA Boeing 727 preparing to land at Washington's Dulles International Airport in adverse weather slammed into a hill, killing 92 persons. Within two weeks, the FAA decided to require that all large jet-powered civil aircraft be equipped with a ground proximity warning system of the type pioneered by Sundstrand.

But even without another such catastrophe, the airlines may still be motivated to outfit their fleets with T/CAS, if only to ensure against willful-negligence suits in case the unthinkable happened. The systems also make good economic sense. If T/CAS prevented only one midair collision, it would more than pay for the cost of outfitting an entire airline fleet. Current estimates are that a T/CAS for an airliner will cost about $75,000; this includes the price of a Mode-S transponder, a system now being developed that will reply to radar and T/CAS interrogations. Less sophisticated versions for smaller business and private aircraft are expected to sell for around $25,000.

U.S. international airlines and foreign air carriers have even more incentive to outfit their fleets with T/CAS. Such carriers operate over oceans or in countries where there is little or no ground-based radar to provide safe aircraft separation. Because the current T/CAS system gets its data from airborne radar transponders that have been standardized by the International Civil Aviation Organization, a T/CAS-equipped airliner will enjoy as much protection against other airliners when flying over central Africa or over the Pacific Ocean as in the U.S.

With approximately 7000 planes in commercial service, the world airline market for T/CAS could reach $500–700 million, according to Frank White, who has been instrumental in the development of T/CAS since its inception and who now serves as a consultant to Sperry Dalmo Victor, a joint venture company. And if the price of a limited-capability T/CAS can be brought down to around $10,000–$15,000, he says, the market for business and private aircraft could match the airline market.

At the moment, the two leading T/CAS contenders are Allied's Bendix Aerospace group and Textron's Dalmo Victor division. Sperry (Phoenix), a major producer of avionics for airline and business aircraft, will market and service the Dalmo Victor T/CAS as part of the firms' joint venture. Rockwell International's Collins Division, another major avionics supplier for the air carriers and the business aircraft market, is watching from the sidelines to see if the market develops. King Radio (Olathe, Kans.), a leading supplier of avionics for business and private aircraft, was recently acquired by Bendix Aerospace. Access to Bendix's T/CAS expertise should give King Radio's designers a head start on the development of a low-cost version that small-aircraft operators can afford.

San Diego replayed. To demonstrate the effectiveness of T/CAS—even if only one of two aircraft on a collision course is so equipped—the FAA and Lincoln Laboratory have conducted extensive flight tests and computer simulations. Lincoln Laboratory went so far as to recreate the San Diego scenario—using a 727 equipped with a T/CAS and a Cessna-172 equipped only with a transponder—during flight tests conducted west of Boston. To provide a worst-case situation, the 727 pilot ignored the initial T/CAS traffic advisory and took corrective action only when commanded to climb. Yet this provided a minimum vertical separation of several hundred feet—more than adequate to have saved those 189 lives.

If a potential conflict arises between two aircraft equipped with T/CAS, the first system to recognize the threat will select an evasive maneuver for its aircraft and will automatically transmit a message to the other to inform it of the planned action. This is essential if both aircraft are flying at nearly the same altitude, lest both T/CAS systems select the same maneuver. In the unlikely event that both T/CAS systems detect the threat at the same instant, special logic built into each system's computer determines which system selects its evasive maneuver first.

Surprisingly, government statistics show that most midair collisions occur near smaller airports rather than near large metropolitan areas where, given the traffic densities, the potential threat would seem to be the greatest. One reason is that the smaller airports serve a wider range of users, including less experienced private pilots. Thus relatively short-haul carriers, such as Piedmont, which make more landings at smaller airports than airlines that fly longer routes between major cities, can expect more frequent T/CAS alerts.

During preliminary 1981–82 tests by Piedmont, when T/CAS data were displayed only to an on-board observer and recorded for later analysis, it was found that the system offered a traffic advisory only once every five hours, on average. This corresponds to about once a day for a typical flight crew. The system detected a collision threat and displayed a resolution advisory much less frequently—about once every 37 hours on average (equivalent to once every two weeks).

Some of the traffic advisories proved to be spurious; they had been generated in the vicinity of an airport by transponders in aircraft that had just landed or were preparing to take off. Dalmo Victor has introduced corrective measures to minimize such false alarms in the T/CAS scheduled for Piedmont's upcoming evaluation.

With FAA funding, Allied's Bendix Aerospace Communications division (Towson, Md.) has developed a version of T/CAS that uses a more sophisticated aircraft antenna that can measure the bearing to another aircraft with much greater accuracy than the Dalmo Victor design—within about 2°, versus around 10°. This enables a T/CAS computer to predict more accurately whether a potential threat is likely to result in a collision or merely a safe near miss, reducing the number of unnecessary resolution advisories. In recent tests by the FAA in the high-density Los Angeles and Chicago areas, the Bendix system demonstrated that it can cut unnecessary T/CAS alerts roughly in half. Also, the Bendix system provides the option of using horizontal escape maneuvers as well as vertical maneuvers.

The main unresolved question about



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Bill Harman of Lincoln Laboratory's technical staff demonstrates an experimental T/CAS adapted for use in helicopters.

T/CAS is how it will interact with the ground-based air traffic control system, which has access to certain information not available to an airborne system. For instance, near an airport where planes are maneuvering to land, T/CAS may signal a potential threat, even though the human controller knows that the other aircraft will be out of the way when it completes its turn to align with the runway. If a T/CAS-equipped aircraft responded to a resolution advisory under these conditions, it could create a conflict with other aircraft in the area.

Although such uncertainties persist, T/CAS computers are programmed to take into account the dense traffic around airports. Most flight maneuvers occur at low altitudes in the vicinity of an airport during landing and takeoff, where even jet airliner speeds are limited by regulations to 250 knots. At such low altitudes, T/CAS automatically changes its computer logic so as to accept a smaller vertical separation before alerting the pilot to take evasive action—that is, 400 feet versus 700 feet for aircraft flying above 18,000 feet. Also, the tau-value at which the system calls for a vertical maneuver is reduced from 30 seconds to 20 seconds to reduce false alarms while still providing safe altitude separations at the reduced speeds.

The FAA has ordered several more T/CAS systems—some from Bendix Transportation Avionics (Fort Lauderdale, Fla.), to be evaluated by United Airlines next year, and some from Dalmo Victor, for trial by Piedmont and Republic. One objective is to assess the system's effect on the ground-based air traffic control system. During these evaluations, and possibly during the early years after T/CAS becomes operational in airline fleets, flight crews may be instructed not to follow a resolution advisory without first radioing the appropriate traffic controller or confirming the threat visually. When experience and confidence are gained, flight crews will likely trust and respond to this latest aid to safe flight as they have to other new avionic developments, such as the color CRT displays that have replaced many of the conventional cockpit instruments in new generations of airliners.

Meanwhile, under FAA sponsorship, Lincoln Laboratory scientists are exploring a variety of ideas in the hope of coming up with a low-cost version of T/CAS that would be suitable for small aircraft. Such a system would, at a minimum, warn of potential collisions with transponder-equipped planes. Every year there are about two dozen fatal midair collisions between small aircraft, resulting in about 50 fatalities.

The challenge facing the developers is to produce an affordable system that doesn't produce too many false alarms. Two decades ago, when the FAA decided to require all airliners to carry radar transponders, the devices cost more than $30,000, making them far too expensive for small aircraft. Today, thanks to advances in microelectronics, a general aviation pilot can buy a very small, lightweight transponder for about one-twentieth the earlier price, even without adjusting for inflation. Thus it is conceivable that an affordable limited-capability T/CAS could become available for private pilots before the decade is over.

Ken Julian is a technical journalist who frequently covers developments in military technology.

For further information see **RESOURCES** *on page 72.*

GO FOR THE PLATINUM

by Ricki and Larry Lewis

The versatile metal is creating new markets in medicine, agriculture, chemical processes, and pollution control



Mention platinum and most people think of fine jewelry and other decorative objects that benefit from the metal's strength, workability, and distinctive pale gray color.

But in fact, such finery accounts for only about 2% of the platinum used in the U.S. New understanding of the metal's unusual biological and chemical properties is increasingly pressing it (and its metallic relatives) into service in medicine, chemical manufacturing, and air pollution control. And while much of this activity is still in the early research stages, many sources are convinced of a potentially enormous market payoff within the next few years.

For example, a platinum atom lies at the core of one of the most promising new cancer drugs. Its strength, corrosion resistance, and biocompatibility also make it an important component of pacemakers, dental bridges, and other, experimental medical devices.

The metal's catalytic properties, while still poorly understood, place it at the heart of a seemingly endless list of chemical reactions. In one, the metal may reduce the dangers of producing methyl isocyanate, the chemical that wreaked havoc on Bhopal, India, late last year; other reactions are employed in fertilizer production, petroleum refining, and the reduction of automotive emissions. In fact, as foreign nations step up their use of platinum-based catalytic converters, and as new technology arises to reclaim platinum from domestic converters, the metal's automotive applications should steadily grow in economic importance.

Fighting cancer. Just as gold-seeking Spaniards accidentally discovered platinum in the 16th century, so did researchers stumble upon its primary medical use—cancer therapy.

In 1969, Michigan State University biophysicist Barnett Rosenberg set out to explore the effects of electromagnetism on bacterial cells. Noting a curious resemblance between the movement of iron filings in a magnetic field and the



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action of tiny fibers in cell nuclei during cell division, Rosenberg grew bacteria in the presence of an electromagnet with platinum electrodes. Ammonium chloride was used as the electrolyte.

The startling result was that the bacteria ceased to divide; instead they grew to 300 times their normal size. Realizing that cancer cells behave in precisely the opposite way (that is, they divide at a runaway pace)—and that some antitumor drugs also produce outsized bacteria—he speculated that an electromagnet might have the same effect on cancer cells as it apparently had on bacteria.

Rosenberg and his co-workers had indeed found a cancer treatment, but it wasn't the electromagnet. Chemists later discovered that a chemical reaction between the platinum of the electrodes and the ammonium chloride produced a powerful antitumor compound called diaminedichloroplatinum (II). In animal studies (and later in human trials), the chemical reduced or halted tumor growth in as many as 80% of the cases.

The chemical exists in two structural varieties, or isomers. In the biologically active *cis* form (called cisplatin), chlorine atoms are attached to one side of the central platinum atom, ammonia groups to the other. In the inactive *trans* isomer, the groups assume an alternating configuration.

Many of the details of cisplatin's workings have yet to be fully unraveled. However, spectrographic analysis suggests that the chemical probably works by forcing itself between the biochemical building blocks of DNA in the cell nucleus, somehow triggering large-scale chromosomal changes that prevent cell division. It is thought that the *trans* isomer is unable to squeeze into the DNA because of its different geometric shape.

Cisplatin received FDA approval in 1979 and is manufactured under the name Platinol by Bristol Laboratories (Syracuse, N.Y.); sales reportedly reached $67.5 million in 1984. For some cancers, notably those of the testes, ovaries, and bladder, cisplatin is now con-

New sources for "little silver"

Platinum was discovered in Colombian rivers by 16th-century Spanish conquerors, who dubbed the metal platina ("little silver"). Thinking that platina was gold that wasn't yet ripe, the Spaniards threw it back into the water for later harvesting. By the 19th century, platina had been identified as a mixture of six heavy metals—platinum, palladium, osmium, ruthenium, iridium, and rhodium—that usually occur together in nature and are now called the platinum-group metals.

Much of the world's supply of platinum-group metals comes as byproducts of nickel or copper mining. Only about 8000 troy ounces (670 pounds) of platinum are mined each year in the U.S., as a byproduct of copper mining by U.S. Metals Refining (Carteret, N.J.), ASARCO (New York), and Kennecott (Stamford, Conn.).

Outside the U.S., the richest natural platinum deposit (and the major U.S. source) is the Transvaal province of South Africa, which is mined primarily for its platinum by three companies. One ton of the ore ultimately yields a pea-sized chunk of platinum. The second largest supplier of platinum-group metals to the U.S. is the USSR, which mines them in northwestern Siberia and the Kola Peninsula near Finland.



INCO LIMITED

Perhaps still smarting from two oil disruptions during the 1970s, several U.S. authorities—including the Congressional Office of Technology Assessment (OTA)—worry over America's dependence on the Soviet Union and South Africa for platinum and other vital metals. One result is the OTA's recent study of supply alternatives in case platinum trade were disrupted for political or other reasons. To combat this "import vulnerability," the report suggests a three-pronged approach: substitution (which is difficult or impossible in many cases), increased domestic production, and new conservation programs.

A platinum source close to home and virtually free of political risk is Sudbury Basin, a two-billion-year-old meteorite crater in Ontario, Canada. In 1982 the site produced 120,000 troy ounces of platinum, versus 900,000 from the USSR and 1.6 million from South Africa. The area is now mined primarily for nickel by Inco (New York).

An even more attractive source is the Stillwater complex in southern Montana. The region—now under joint study by Manville, Chevron U.S.A., and Anaconda Minerals (all in Denver)—could yield 5500–8500 troy ounces of unrefined platinum per ton of refinery feed, according to the U.S. Bureau of Mines.

"In the last year or so we've been evaluating the feasibility of operating there, including the economics of the minerals market," says Cliff Bowers, manager of corporate relations for Manville. Factors that may delay the project, perhaps indefinitely, include the region's inclement weather and the possibly adverse environmental impact. A decision on the complex may be reached by the end of this year, says Bowers.

The Stillwater project just might put the U.S. on the platinum map. In view of the recent volatility of platinum market prices, however, it's almost impossible to get a firm handle on the economics involved. Operating costs for domestic deposits have been estimated by the Bureau of Mines at $500 per troy ounce of refined platinum. The market value of platinum, however, has bounced between less than $300 per ounce to more than $1000 in recent years.

Until the Stillwater question is resolved, domestic platinum is more likely to come from the industrial scrap heap than from mines or meteorite craters. A recent Inco study, sponsored by the Bureau of Mines, identified one underutilized platinum source: recycled automobile catalytic converters. These now supply about 10% of domestic platinum, but the diligent recovery of every such device could supply up to 35% of the nation's needs—and some two-thirds of the auto industry's requirements for new convertors—according to Sebastian Musco, president of Gemini Industries (Santa Ana, Cal.), a platinum reclamation company. For now, no one knows what happens to most of the automotive platinum in the U.S.; much of it almost certainly ends up in landfills. And of that metal which might be salvageable, large amounts are "poisoned"—so heavily contaminated that economical recovery is impossible—by drivers who use leaded gasoline.

Although it was for General Motors that Gemini originated and developed the technique for reclaiming platinum and palladium from catalytic converters, most of the company's business comes from oil companies that use platinum catalysts for converting crude oil to gas. "Once they use a catalyst a number of times, it becomes dirty, or 'spent,' and loses some of its catalytic action," says Musco. "We first analyze the mixture of products we receive, then claim the platinum metals in the catalysts, produce pure platinum, and return it to the suppliers." The company also recycles catalysts used in the production of aspirin substitutes, saccharin, and other drugs.

sidered the best treatment. The drug has also been successful in clinical trials on cancers of the cervix, uterus, esophagus, lung, bones, prostate, and head and neck, as well as on some pediatric cancers.

Cisplatin is also effective against the Roux sarcoma virus that causes cancer in chickens. This virus is unusual in that its genetic material is RNA (ribonucleic acid), rather than the more common DNA. Cisplatin's power against the chicken virus suggests that the drug might be developed into a therapy against a recently identified family of RNA viruses in humans, such as HTLV (human T-cell leukemia virus, implicated in some leukemias) and AIDS (acquired immune deficiency syndrome).

Protecting healthy cells. Unfortunately, like many chemotherapeutics, cisplatin has some nasty side effects, including severe nausea and kidney impairment. The reason is that drugs that interfere with cancer cells also attack healthy cells, such as those of the digestive system. And as the kidneys struggle to rid the body of the toxic drug, many of their structures become damaged.

Platinol is now the only platinum drug available, but several others are on the horizon. One of the newcomers, Bristol Labs' carboplatin, is said to be far less toxic (although no one knows why). Chemically, carboplatin is *cis*-diamine-1-1-cyclobutane dicarboxylate platinum, in which the chlorine atoms of cisplatin are displaced by carbon-containing groups. Preclinical trials of carboplatin were conducted at London's Royal Marsden Hospital, and the drug has been submitted for marketing approval in the United Kingdom.

Yet another class of platinum antitumor drug, under development at Engelhard (Iselin, N.J.), has a platinum atom bonded in the *cis* configuration to one or two molecules of vitamin C. The vitamin was selected largely because it is nontoxic and is well tolerated by the body. The drug is now in the preclinical research stage, according to Eric Stern, Engelhard's chemotherapy program manager.

Even in cases where platinum drugs are less than desirable, other platinum-group metals may offer alternative therapies. One example is a compound based on palladium. The drug could be useful in areas of the body, such as the digestive system, that have naturally high concentrations of chloride ion, which interferes with cisplatin's action. "Even if a cell has a high chloride content, it can still react with the palladium drug," says Michigan's Rosenberg. "This compound might thus be useful in gastrointestinal cancers, for which there really is no good therapy."

Several animal studies suggest that cisplatin and other platinum compounds may also one day play a role in fighting viral, bacterial, and parasitic infections. In one such study, cisplatin cured mice infected with the parasite *Trypanosoma rhodesiense* (which causes Rhodesian sleeping sickness in humans) with an efficiency of 92.5%. Although sleeping sickness is extremely rare in the U.S., there are certain immunological similarities between the disease and AIDS that could spur a new round of research by pharmaceutical companies.

If cisplatin does prove to be an effective antibiotic, however, its toxicity may restrict its use in humans to topical applications or antibiotic-resistant, life-threatening infections (although its side effects can be limited by combining it with other agents).



MICHAEL LA RICHE

Researcher Burgess demonstrates Zeise's salt, which contains platinum. Milkiness denotes the presence of hepatitis virus.

Platinum also shows promise as an important new diagnostic tool for hepatitis and other disorders. One application is Zeise's salt, a highly reactive compound containing platinum, ethylene, chlorine, and potassium. The compound has been used as a general chemical reagent for more than a century. More recently, though, researchers have found that the platinum component binds to unique surface proteins (in much the same way as it reacts with the DNA of cancer cells) on the cells of patients with hepatitis B, rheumatoid arthritis, and the connective-tissue disease called lupus erythmatosis. The hepatitis virus is revealed in just a few seconds by the formation of a precipitate, and the test can be performed by relatively untrained personnel.

Despite the compound's seeming utility, however, several companies abandoned research on Zeise's salt because of its apparently high false-positive rate (the number of patients falsely identified as carrying the disease). But recent data may put that problem in a new light—particularly the discovery of a new type of hepatitis virus, called the delta form. "The compound detects not one but several hepatitis forms," says Thomas Burgess, manager of the departments of special chemistry and immunology I at SmithKline Bioscience Laboratories (King of Prussia, Pa.). Working with chemistry professor Saul Shupack, Burgess studied the compound at Villanova University (Philadelphia) during the late 1970s. The discovery of new hepatitis forms has convinced both researchers that the seeming false-positive problem had arisen because the salt had been spotting organisms that went undetected by other methods.

Burgess and Shupack have filed a patent renewal and hope to make the preparation the basis of a new commercial diagnostic kit. Unlike existing kits, this one would screen for all known types of hepatitis, including A, B, the delta form, and the type known as non-A, non-B. If approved, the kit could be produced under license by an existing company.

Body work. Metallic platinum has also been put to work inside the body—as corrosion-resistant capsules containing radioisotopes, for example. When these capsules are implanted into tumors, the biocompatible platinum prevents the body from rejecting them. Thus held firmly in place, they deliver virtually all the radiation to the malignant cells, with little or no damage to nearby healthy cells.

In this procedure, steel tubes are first



Biocompatible platinum leads are used on 3M's cochlear implant, a promising aid for the profoundly deaf.

passed through the tumor, then replaced with plastic tubes. The platinum-coated radioactive "seeds" are passed into the tumor through the tube (which allows the implants to be introduced quickly, thus minimizing personnel exposure). Encapsulating the radiation source in platinum further protects personnel against harmful beta and low-energy gamma radiation, while permitting higher-gamma radiation to pass into the malignant cells.

On yet another medical front, researchers frequently use platinum-based microelectrodes to unravel the complexities of the nervous system. In some cases, a lone cell can be penetrated with a hair-thin platinum alloy. Researchers can thereby isolate the cell and study its activity with respect to its neighbors.

Platinum electrodes were once relegated to studying the giant nerve cells of animals such as the squid. Now, having shrunk considerably, they're showing up in the human ear in the form of cochlear implants—essentially "artificial ears" for the profoundly deaf, many of whom cannot benefit from conventional hearing aids (HIGH TECHNOLOGY, Oct. 1984, p. 102). The recently approved implant manufactured by 3M (Minneapolis) and several others on the drawing board use silicone rubber–coated platinum-iridium wires that wind through the twisted channels of the inner ear. The silicone prevents the wire from bumping into the delicate walls or rupturing nearby compartments that could release potassium and destroy the auditory nerve.

Platinum catalysis. By far the main use of platinum is as an automotive and chemical catalyst (a substance that speeds reaction rates, often a millionfold or more). One of the most valuable features of a catalyst is that it is used in very small amounts (typically in parts-per-million concentrations); nevertheless, approximately 563,000 troy ounces (47,000 pounds) of platinum were used in these applications by U.S. industry in 1982, some 72% of the total consumption.

As in its pharmaceutical applications, very little is known about how platinum (or nearly any other metal) promotes specific reactions. It is thought that most catalysts react temporarily with the chemicals being altered; some of the molecules' internal bonds weaken and break during this momentary binding, permitting a specific rearrangement of some of the reactive subgroups. One example is petroleum reforming, in which the octane number of gasoline is increased by platinum-based catalysts that break large molecules apart, then reassemble them in new configurations.

Platinum's chief catalytic role in the U.S. is in the catalytic converters in automobile exhaust systems—an area which is increasingly marked by chemistry and design innovations and which promises to create new international markets in the near future. Meanwhile, the domestic market for these catalyst systems (usually installed in the finished converter by the automakers) is highly competitive, estimated by one producer at well over $100 million a year. Leading suppliers include Engelhard, UOP (Des Plaines, Ill.), W. R. Grace (New York), and Johnson Matthey (Malvern, Pa.).

The main differences between these companies' products are the catalyst's composition and how it is immobilized (that is, secured onto a supporting matrix of steel or aluminum pellets). Because of strict secrecy agreements with automakers, details on converter chemistry and design are scarce. Nevertheless, Johnson Matthey has disclosed the key feature of its improved (though still experimental) converter: While existing models operate in two steps—first converting nitrogen oxides to nitrogen and hydrocarbons to water, then converting the carbon monoxide to carbon dioxide—the new device handles all three reactions simultaneously. The company also claims that the converter is more durable than its predecessors and less likely to decompose at high temperatures.

Demand for platinum in this application is almost sure to expand, especially in view of rapidly changing air quality regulations here and abroad. This summer, for example, West Germany will introduce a tax incentive for using catalytic converters, and next year Australia is expected to require the devices on cars. Because the technology originated in the U.S., says a Johnson Matthey spokesperson, these trends almost certainly mean new sales of catalyst systems for American producers, many of whom will probably establish new production sites abroad in order to avoid the heavy metal's stiff shipping costs.

Platinum catalysts have also become industry workhorses in the manufacture of chemicals, especially for agricultural uses. One notable example is a new platinum-iodine catalyst—developed by Petrochemical Research Laboratories, a division of Japan's Asahi Chemicals—used for safer production of carbamates. These compounds are important intermediates in the synthesis of isocyanates, which are in turn used to produce pesticides and herbicides. In the past, carbamate synthesis relied on phosgene, an extremely toxic chemical used as a weapon during World War I.

Another agricultural application is in the fertilizer industry. Platinum-rhodium rods molded into fine mesh at Johnson Matthey and Nitram (Tampa, Fla.) provide a catalytic filter through which ammonia and air enter and nitric oxide exits. The oxide is then converted to nitrate fertilizer.

Whether platinum's utility will continue to grow is still uncertain, especially in view of its unstable price and supply (see "New sources for 'little silver' "). But many researchers are convinced that today's platinum technology offers the merest glimpse of what is to come, especially in cancer therapy. If they are correct, the metal is certain to move steadily up the list of the world's key materials. □

Science writer Ricki Lewis teaches human genetics at the State University of New York (Albany). Larry Lewis is a chemist at GE's R&D Center (Schenectady). Both hold PhDs from Indiana University.

For further information see **RESOURCES** *on page 72.*

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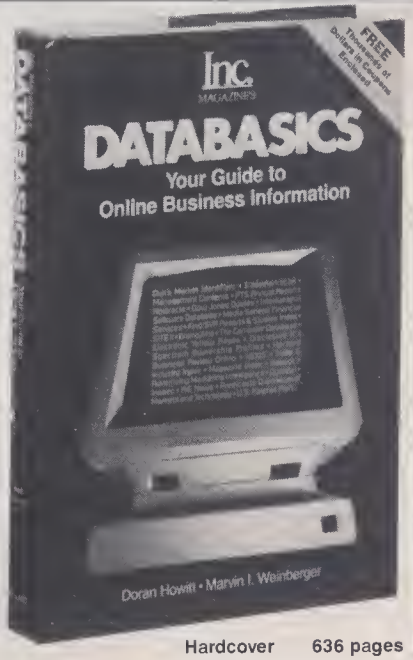
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HELPING HANDS FOR BIORESEARCH

Lab robots could speed the search for new medical products and processes

Intense competition in the biotechnology and pharmaceutical industries is creating a brisk new market for time- and labor-saving automated devices. One result is a new breed of technician—the laboratory robot, which boosts productivity by freeing its human counterparts for planning, data interpretation, and other creative tasks. With mechanical and electrical self-monitoring routines, the instrument can be programmed to perform intricate multistep tasks unattended, 24 hours a day.

For example, many biotechnology companies are evaluating unique proteins called monoclonal antibodies (MAbs) for both diagnosing and treating disease. MAbs are produced by combining two types of cell into a new cell, called a hybridoma; often, thousands of these hybridomas are screened before researchers select candidates for further evaluation. Obviously, the more cells that can be efficiently screened in a given period of time, the better the chance of commercial success. Hence this job is ripe for automation. Similarly, robots can help companies that are screening new compounds for antimicrobial or antitumor activity perform thousands of biological assays each year.

Several types of lab robotic systems have evolved, with the capabilities of one type often overlapping those of another. Some, for example, simply carry samples between analytical instruments, which are placed within easy reach of the robot arms. Others are actually automated laboratory workstations with discrete analytical instruments built into the robotic arm; all procedures are carried out in one place, under the control of the workstation's microprocessor. Still other robots combine these capabilities in a single design—when the robot itself cannot perform the analysis, it can access other instruments.



A Zymate robotic arm is controlled by an automated titration system (right, rear), which determines sample concentrations. By changing hands at the "parking station" (foreground), the robot also has access to sample tubes and the balance (left).

ZYMARK

One relatively simple example is the Zymate lab robot, introduced in 1981 by Zymark (Hopkinton, Mass.). Selling for about $35,000, it basically consists of a robot arm and several interchangeable modules. The arm can move samples from one location to the next and, with the appropriate modules, can withdraw samples, pour liquids, and perform other complex tasks.

In addition, Zymark provides the customer with new instruments when needed. With one system, the company had to build and integrate a customized centrifuge. "A centrifuge is an instrument that ordinarily must be watched," says president Frank Zenie. "A technician loads it correctly, and when it has finished spinning, he notes where the rotor has stopped and withdraws the samples. We therefore had to develop a centrifuge that can tell the robot arm where the samples are."

Basic laboratory requirements have also called for the design of more sophisticated hardware. When processing samples, for instance, technicians routinely unscrew caps, add reagents, and reseal the containers—simple tasks for a human, but complex for a robot. Zymark designed a variety of grippers so that the robot arm could grasp and uncap different-sized containers.

Radian, an Austin-based engineering services organization, entered the laboratory robotics field in 1983. As an IBM-licensed value-added retailer, Radian modified the basic IBM 7565 robot for lab use. "We first believed that the major market for such systems would be in the handling of biohazardous materials, such as carcinogens," says Terry Hight, Radian's program manager

by William E. Rhodes III

for laboratory robotics. "But we later found that there are many instances where automation extends to other, more conventional areas as well."

Radian works with customers to identify lab tasks amenable to automation, evaluates the options, and then develops the software and peripheral hardware. "Field service and customer support are very important in this business," says Hight, particularly since the Radian system sells for about $120,000.

Unlike the Zymate, which is only about 2 feet tall and 15 inches square, the IBM unit measures 7 × 3 × 6 feet and weighs more than 1000 pounds. And while Zymate has been criticized for its slow speed and less than ideal gripper flexibility, the Radian robot processes samples very rapidly, maintains an extremely high level of precision, and has a sophisticated pressure-sensitive hand that can manipulate a variety of labware. IBM initially designed the system for internal use in non-chemistry-lab applications; Radian has outfitted the system for a number of pharmaceutical and chemical laboratory procedures.

Even though laboratory robots must often be tailored to a customer's special needs, many applications are routine enough to make a mass-produced robot feasible, says Brent Keller, director of marketing for Infinitek (Sunnyvale, Cal.). The company offers what it calls a "laboratory workstation" that combines sample preparation and analysis in a single instrument. A prototype, called the Infinitek 1000, has been tested and enthusiastically received in several of the San Francisco area's biotechnology companies, according to Keller.

In contrast to Zymate, the instrument is designed for laboratories that routinely perform large numbers of biological assays. It features a track system on its base that allows it to move reagent and sample containers, and it can perform a variety of colorimetric assays (analyses based on color changes in the reagents). Although its robot arm cannot pick up, manipulate, or carry a sample container, it is fitted with instruments for processing samples.

Perkin-Elmer (Norwalk, Conn.) also entered the field early this year, announcing several devices that together



Some robotic grippers offer tactile sensing capabilities and seven degrees of freedom for complex sample handling.

make up its lab automation system. The heart of the system, a 60-pound Mitsubishi robot with a 26-inch reach, can be linked with other Perkin-Elmer products such as spectrometers, chromatographs, and computer graphics software packages. The entire system is controlled by a personal computer.

"The finished system depends entirely on the customer's application," says Anne Cerino, senior marketing specialist. "It could consist simply of an automated balance for weighing samples, but it could also be much more complex, requiring the robot to interface with several other devices." She adds that while the system could be used in virtually any laboratory setting, it is being marketed primarily to pharmaceutical and biochemistry customers. The robot, with computer and software but without add-ons, sells for about $20,000.

Customers generally find that laboratory robots increase productivity, but there has been some initial employee resistance. Jim Johnson, director of quality control for Becton Dickinson's immunodiagnostics division (Orangeburg, N.Y.), says his laboratory technicians hesitated to use the Zymark system at first, afraid that the robot was competing for their jobs. This fear may not have been groundless; Johnson acknowledges that the robot allowed him to forgo replacing a retiring employee. But there has been a positive impact as well, he says. Once technicians realized that the robot could be programmed to perform tasks that are tedious or inconvenient, such as running assays on weekends, they began to accept it.

The payoffs of lab robots are becoming clearer. But because they are still a novelty, and because so many of them are designed for a specific task or customer, it's hard to predict how much of the analytical instrumentation market they can command. Worldwide, that market totaled some $3 billion last year, according to Perkin-Elmer, and the U.S. accounted for about a third of it.

With more than 300 biotechnology companies in the U.S. alone, however, robot manufacturers have plenty of incentive. In fact, this segment could account for at least 1000 basic robot placements (at an average price of $35,000 each), thanks to the diversity of tasks performed in each company and the fact that many customers maintain multiple laboratory sites. (Zymark's Zenie notes that 60% of the company's accounts are multiple users, with one customer employing no fewer than 17 systems.) If hospitals, clinics, and other conventional healthcare research sites are included, the potential market could easily reach hundreds of millions of dollars a year.

Robots are not without their problems. As they become more complex, for example, the price may rise precipitously (especially if the device is custom-tailored); for some research labs it would be cheaper to continue doing the work by hand. Moreover, frequent design changes and adaptations to new procedures must be handled quickly and economically.

Despite such limitations, the use of lab robotics is expected to grow at a healthy clip as pharmaceutical and biotechnology competition heats up during the next few years. By automating support and R&D laboratories, these workers should help identify and produce new healthcare products and bring them to market faster. □

William E. Rhodes III is president of Rhodes Associates, a biotechnology and pharmaceuticals consulting firm in Westfield, N.J.

RADIAN

FOILING CORPORATE SOFTWARE PIRATES

Vendors search for "locks" that won't deter paying customers

Many personal computer software vendors would like to get rid of half their user bases—the half that's ripping them off to the tune of nearly $1 billion a year through the unauthorized copying of software. Such theft is often perpetrated by individuals, ranging from users who make copies for their friends to sophisticated thieves who copy programs in large quantities for illegal resale. But perhaps even more damaging to the software vendors is piracy by large corporations, which often copy and distribute programs for internal use.

Vendors of the most popular, and hence most pirated, programs are desperate to stem the flow of illegal software and capture the potential revenues it represents. But conventional copy protection schemes have proved futile and perhaps even counterproductive—they can sometimes frustrate legitimate users. Now some vendors are considering sophisticated "lock and key" protection, although the move could face stiff resistance from a market that is leery of the additional costs and inconvenience.

PC software piracy first gained momentum among hobbyists eager to swap utility and game software, sometimes within clubs formed for that purpose. Now enterprising pirates circulate entire catalogs of cut-rate software for hobbyists. Software swapping has reportedly become a way of life in educational institutions from colleges to elementary schools, and the federal government is said to do a fair amount of softlifting itself. But schools and government make nebulous targets, so most of the antipiracy attention has been focused on corporations. Besides, that's where the real PC software money is: over $3 billion spent this year, according to market research firm Future Computing (Richardson, Tex.).

The software industry has been grumbling for years about staggering losses to piracy by corporate PC users. But only recently have numbers been attached to the problem. A study by Future Computing found that corporations harbor as many unauthorized copies of PC software as legitimate copies. Its report puts the total retail value of the bogus software at around $10 billion and estimates that if a quarter of the illegitimate users are potential customers, the industry will lose $800 million in revenues this year. Lotus Development (Cambridge, Mass.), Ashton-Tate (Culver City, Cal.), and Micropro International (San Rafael, Cal.) alone are being bilked for $100 million annually, according to George Colony, president of Forrester Research (Cambridge, Mass.); other estimates range considerably higher.

A study by Future Computing found that corporations harbor as many unauthorized copies of PC software as legitimate copies.

Corporate America, which is not about to publicly sanction widespread piracy, has been establishing internal auditing procedures designed to limit the spread of phony software. But candid conversations with corporate PC users indicate that pirated software is still commonplace in many large organizations. "I have more copies of Lotus 1-2-3 than I know what to do with," admits one midlevel manager at a major financial institution in Chicago. Using copied software has become something like fudging on taxes: a simple, low-risk, and culturally condoned way to save a little money.

The PC software industry's traditional defense against piracy is diskette copy protection, which generally involves altering the program diskette or the way information is recorded on it to baffle the copy routines that are a part of any personal computer's operating system. Several protection schemes change the way a diskette is "formatted"—that is, the way in which information is physically organized onto tracks (analogous to grooves on a record). Because tracks are divided into "sectors," the commercial copying machines used by vendors can purposely skew or mislabel sectors, and access special tracks. Other schemes use a laser to burn away small patches in the diskette's magnetic coating. PC disk drives have no trouble reading the altered diskettes. But when they try to copy them, the operating system detects the irregularities and returns an error message.

Users can get around all this and make duplicates with the help of utilities called "bit copiers." These programs instruct the disk drive to reproduce every magnetic pulse from the master diskette, without regard to track, sector, or any kind of irregularity. Merely obtaining a copy isn't always enough: Some high-powered business software, like Lotus's 1-2-3 and Ashton-Tate's Framework, instructs the disk drive to periodically check the program diskette for identifying irregularities (such as a laser mark) that won't show up on a copy containing only the original's magnetic information. But again, no problem. A simple "patch" program can be placed in memory to wait for the instruction to check the diskette. The patch intercepts the request and tells the main program that all is well. Software vendors try to frustrate patches by periodically varying the location of the instruction for which the patch is waiting, but the new locations usually appear on users' bulletin boards within two weeks. To date, the protection schemes seem to have had little impact on the pirates: The Future Computing study indicates that supposedly protected programs are copied as often as

by David H. Freedman

unprotected programs.

One needn't be rich or brilliant at programming to use bit copiers and patch programs. They are easy to use and are available from a number of vendors, at a fraction of the price of a typical business package. Such "lockpick" programs are perfectly legal and are widely advertised in computer magazines (although many publications, under pressure from software vendors, won't accept such advertising). Ironically, vendors that protect their software may be doing more for lockpick vendors than for themselves. Central Point Software (Portland, Ore.) is pulling in over $6 million annually from sales of its $40 Copy II lockpick software. Michael Brown, Central Point's president, is anything but apologetic about the way he makes a living. "We believe very strongly that what we're doing is not only right but necessary," he says. "We're responding to a market where there is inadequate customer service."

Brown's rationale is that protected software prevents legitimate users from making backup copies and from installing the programs on a hard disk. Vendors usually supply a backup copy of their software and will exchange damaged diskettes for new ones; some programs allow users to make one or two copies before the protection scheme kicks in. But many users say a few copies aren't enough and insist on the right to copy programs at will for archival purposes. Because protected software has to remain on the original diskette, a user of hard disks can't reap any of their speed or convenience benefits. Some vendors, including Micropro and Ashton-Tate, have been experimenting with protection that allows programs to be copied to hard disks, but so far the results have been mixed; Micropro has already abandoned the scheme.

One way to improve antipiracy protection without preventing archival or hard disk copying is to move to hardware-based schemes. Here a program is instructed to check the computer hardware for a unique feature, such as a serial number embedded in a chip, that will identify the system as one authorized to run the program. The idea isn't new: Since 1979, Metafile Information Systems (Rochester, Minn.) has sold its data management application programs with a customer-installed hardware device that "unlocks" the software. But the industry has stayed away from the concept, because it is expensive and because many legitimate users run a package on more than one system—particularly in large corporations, where machines are routinely shuffled around.



One of the most common methods software vendors use to thwart pirates is to overlay or mislabel a disk's pie-shaped "sectors" (alterations shown here in simplified form). The computer's operating system can read such modified disks but is unable to copy them. With overlaid disks, the disk drive's head typically can't move in the patterns required for copying them; with mislabeled disks, the system ignores information in sectors labeled with numbers it isn't expecting.

Recently, though, schemes based on hardware have received new impetus, thanks to an ambitious campaign by the Association of Data Processing Service Organizations (Arlington, Va.). ADAPSO's proposed "Software Authorization System" is a three-part standard: a hardware "lock," which attaches to the personal computer's serial communication port without preventing it from being used with other devices; a hardware "key," resembling an office key, which would be supplied with a software package for insertion in the lock; and software "tumblers," consisting of instructions embedded in the program, which communicate with the lock to ensure that the key is valid.

The association intends to make the system's specifications available to the industry, leaving the manufacturing of the lock to third-party suppliers and the development of keys and tumblers to individual software vendors. Programs could incorporate different levels of protection: something as complex as encryption algorithms that are decoded by a chip embedded in the hardware key, or something as simple as an instruction routine that merely checks the serial number of the lock (which the program would learn the first time it ran).

Under the ADAPSO scheme, users would be free to make backup copies and install programs on hard disks. Programs could also be run on different compatible PCs, as long as the users retained the appropriate key for each program. (In the case of programs that look for lock serial numbers, the lock itself would have to be moved to the new machine.) What's more, bootleg copies would be useless without the right key—and chip-based keys would be exceedingly difficult to duplicate. Finally, the software would periodically recheck for the right key or lock, to prevent someone from starting up a program and then transferring the key and/or lock to another PC.

There is still the drawback of cost. Locks, of which most users would need only one, will probably cost about $25; keys, and the implementation of the protection, might add anywhere from $2 to $10 to the price of a software package. Software vendors may initially have to throw locks in with their

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packages to get the scheme off the ground. But the plan seems to have the tentative backing of most of the major business package vendors, and it could find its way into products some time next year.

The corporate response to the ADAPSO plan, however, is less than enthusiastic. In fact, the New York–based Microcomputer Managers Association, whose member corporations purchase some $200 million worth of PC software annually, is adamantly opposed to the plan. The MMA objects that the scheme wouldn't be foolproof, that it would entail unacceptable costs and inconveniences without benefit to the user, and that piracy within corporations isn't nearly as widespread as the industry makes it out to be.

Even the most virulently pirate-hating software vendors recognize the need for restraint.

As a counterproposal to the ADAPSO plan, the MMA suggests "site licensing," whereby companies pay a fee to the software vendor for the right to duplicate a software package for their employees. A site license can save corporate PC managers anywhere from 10% to 50% of the cost of buying individual copies, and it short-circuits the issue of piracy, at least within the licensed site. But so far only a handful of vendors are offering site licenses. Most, like Lotus, prefer to retain the higher revenues generated from individual sales and continue to fight piracy with protection schemes.

What software vendors can't do with technology, moreover, they will likely try to accomplish with fear and education. The fear will presumably come from the increasing number of lawsuits leveled at corporations caught pirating. Lotus alone has nailed four companies, and other vendors—with the support of ADAPSO—are ready to follow. Copyright law is a little fuzzy on the subject of software protection, but Congress and the Supreme Court are expected to take a clearer stand against piracy in the near future. As for education, ADAPSO has distributed 60,000 copies of an antipiracy brochure to schools and businesses. The campaign has already picked up at least one unlikely ally: Central Point Software is including the brochure with each copy of its protection-breaking program.

Interestingly, some vendors aren't all that upset about piracy. Smaller companies struggling for market share sometimes see copying as a sort of free advertisement. Most pirates wouldn't buy the software even if they couldn't copy it, contends Jay Honeycutt, president of Computer Group (Boston), a utility software vendor. But a potential customer presented with an unauthorized copy might like it and go legitimate out of a sense of fair play or a desire to obtain documentation and support. Also, some believe the reputation gained by programs that are widely copied translates into a good deal of legitimate business. "If a bootlegged copy leads to a sale," says Honeycutt, "it's worth it."

Most of the industry takes strong exception to that point of view, but even the most virulently pirate-hating software vendors recognize the need for restraint. For example, vendors could resort to mining their software with powerful weapons such as "worms"—hidden miniprograms that can destroy an illegally copied program along with data and any other software residing in the system. But Vault Corp. (Westlake Village, Cal.), a leading designer of protection schemes, found vendors unwilling to be publicly associated with worms in any form. Powerful weapons, after all, can backfire powerfully; the destruction might be seen as poetic justice for pirates but wouldn't outweigh the ethical, legal, and marketing problems that could result if the worms accidentally attacked legitimate users' files. No matter how concerned they are about losing revenues to pirates, vendors apparently aren't ready to risk sliming the hand that feeds them. □

David H. Freedman is a senior editor of Infosystems.

IN THE WINGS: SELF-REPAIRING JETS

Sophisticated flight control systems will offset damage and cut maintenance cost

A delta-winged fighter plane knifes through the sky toward a high-priority ground target. Only minutes from the target, an antiaircraft round hits the plane, reducing the outer third of the left wing, including its aileron, to twisted metal. Within seconds, the fighter's flight control system analyzes the damage and advises the pilot that other control surfaces can be used in place of the damaged aileron to perform the attack run. On the basis of this information, the pilot completes the mission and returns safely to base.

This scenario illustrates one of the benefits of a new "self-repairing" (or, more properly, "reconfigurable") flight control system being developed by the U.S. Air Force's Aeronautical Systems Division at Wright-Patterson Air Force Base in Ohio.

Initial efforts are being directed toward a system for tactical fighter aircraft, but once it is fully developed, the system could become available to a wide range of military and civilian aircraft, including airliners.

The program has four basic goals, according to Duane Rubertus, the Air Force's laboratory manager for this project. The first is "to be able to recover from damage to a point where the pilot can achieve his original mission, with the aircraft providing information to the pilot on what it is still capable of doing. If the original mission is out of the question, then the second goal is to perform an alternate mission before the aircraft returns to base.

"If neither of those alternatives is possible," says Rubertus, "our third goal is to recover the aircraft at a friendly base. Failing that, our fourth goal is to have the aircraft flyable to the point where it can at least reach friendly territory and remain stable long enough for the pilot to bail out."

Currently, pilot controls in the cockpit are linked to movable surfaces that alter the wings' lift and hence the orientation of the aircraft. When the pilot moves the cockpit controls, the flight control system chooses the correct combination of control surface deflections, according to rigid flight control "laws," to execute the desired maneuver. Each flight control surface is vital to the safe operation of the aircraft. If an elevator, aileron, or rudder failed, the aircraft could become uncontrollable during some phases of flight. Yet the flight control laws assume that all control surfaces are available. Consequently, most advanced control systems incorporate a high degree of redundancy.

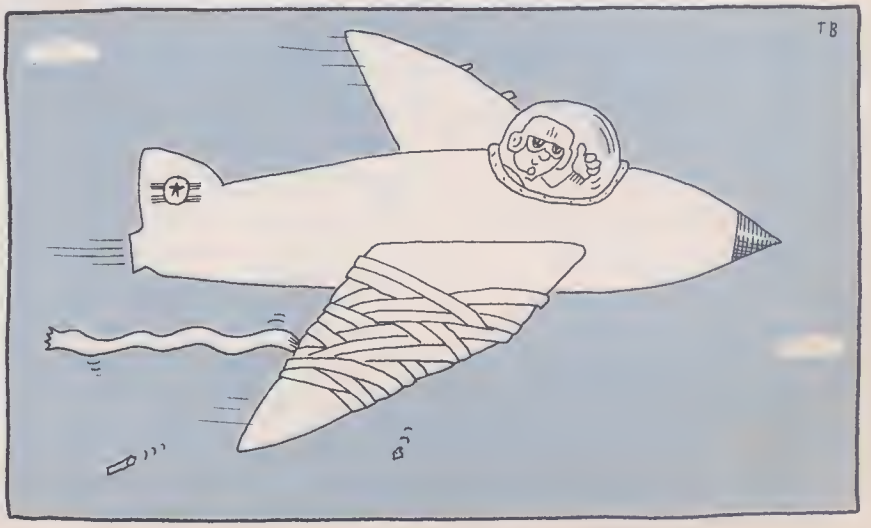
In contrast, the new system being developed by the Air Force will be more flexible. It will continually evaluate the aerodynamic condition of the aircraft, and if any control surfaces are unavailable because of malfunction or battle damage, the system will "reconfigure" itself to complete the desired maneuver.

In the opening scenario, for example, the self-repairing system would act as follows: Sensors in the left wing would advise the system that the left aileron was inoperative. The aircraft's inertial reference system would sense that the aircraft was banking and would provide instructions to the flight control computer. A command would then travel to a reconfiguration module, which would instruct the left flap to deflect to compensate for the loss of lift from the damaged wing. From this point on, maneuvers commanded by the pilot would be accomplished through the reconfiguration unit, which would manipulate the aircraft's left and right flaps, spoilers, and right aileron. The system would also advise the pilot of the aircraft's remaining capabilities so that he could decide whether to continue the mission or return to base.

Besides saving lives and aircraft in combat, the self-repairing flight control system would have important economic benefits. No single control surface would be critical. "With such a system," Rubertus explains, "we would be able to place more reliance on the aircraft as a whole. It would no longer be only as 'healthy' as its weakest part."

In a combat situation, this would mean less time required for maintenance and hence higher sortie rates. This, in turn, would mean fewer aircraft needed to achieve a given degree of mission success. In civilian aircraft, such a system would reduce maintenance time while improving reliability and safety.

The program got underway in October 1984, when the Air Force awarded the first of a series of multiyear con-



TOM BLOOM

by Jeff Richmond



Bridalveil Fall, Yosemite National Park, California c. 1927. Photography by Ansel Adams. Courtesy of the Ansel Adams Publishing Rights Trust. All rights reserved.

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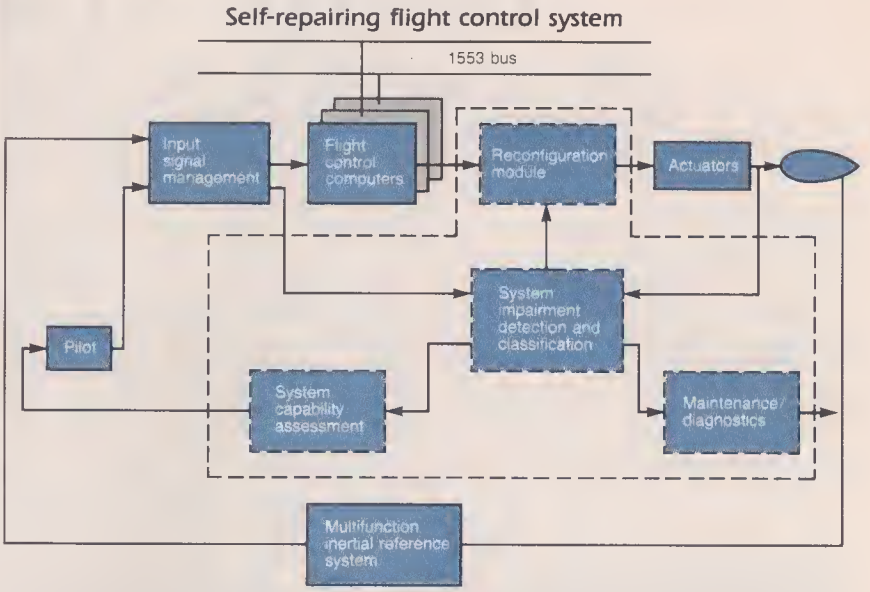
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The wiring diagram indicates schematically how a self-repairing flight control system might be installed. Solid lines indicate components that are part of existing systems. The broken lines indicate the anticipated components of the reconfigurable flight controls. The system would also incorporate a diagnostic subsystem to help ground-support personnel locate malfunctions.

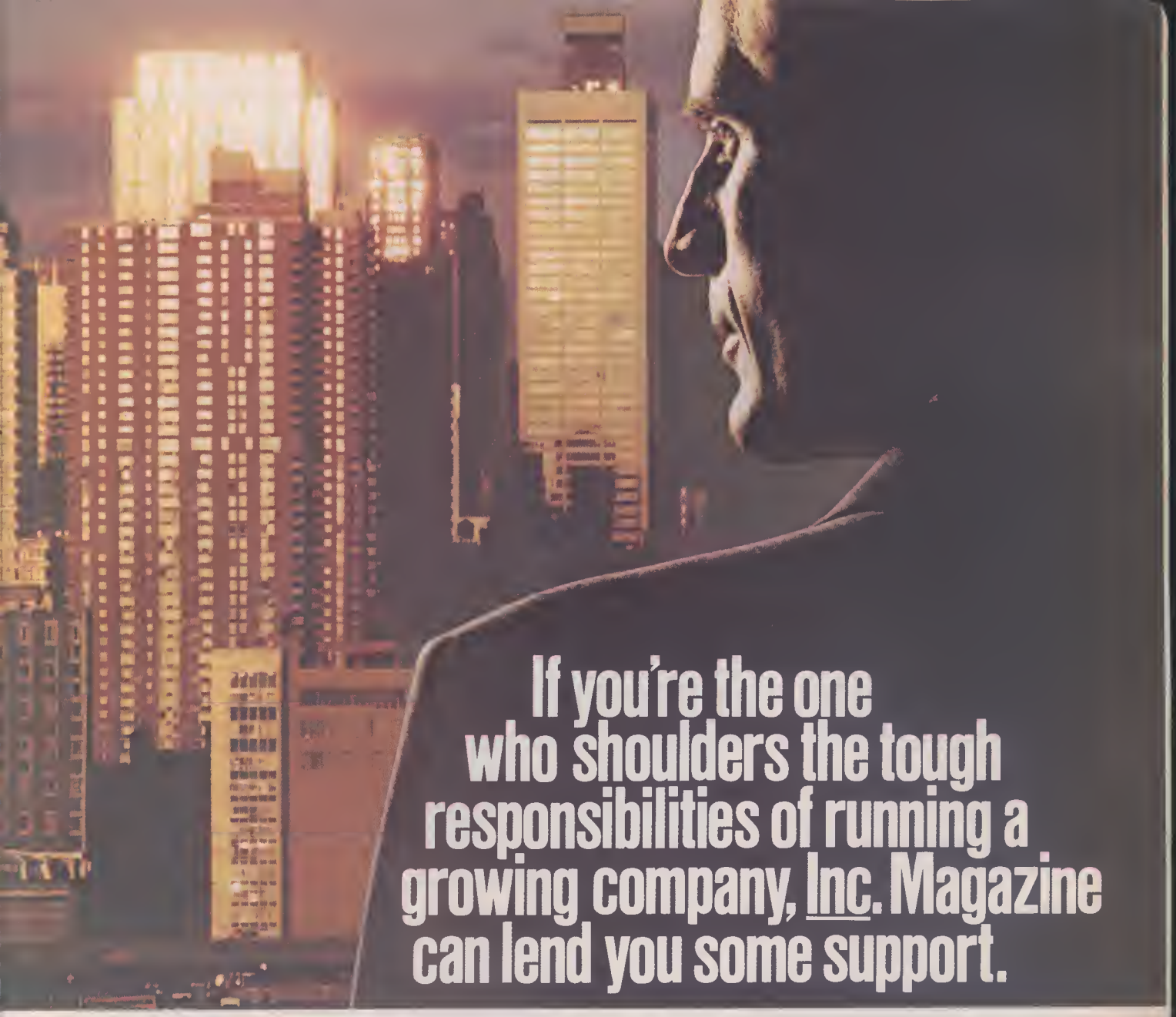
tracts totaling nearly $8 million—all for conceptual development of one or more elements of self-repairing systems. The two largest awards went to Honeywell in Minneapolis ($2.2 million) and McDonnell Douglas in St. Louis ($1.6 million). Honeywell will begin development of a diagnostic system to be used by maintenance technicians at bases where resources are scarce. McDonnell Douglas will design and eventually build an improved inertial measurement unit of the type needed to instantaneously provide aircraft attitude data to the reconfiguration module.

Other major contracts were awarded to Grumman Aerospace (Bethpage, N.Y.) and General Dynamics (Fort Worth, Tex.) to develop reconfiguration strategies. One of these companies will eventually be selected to demonstrate and evaluate a prototype reconfiguration module on a tactical aircraft. Lear Siegler (Dayton, Ohio), Charles River Analytics (Cambridge, Mass.), and Scientific Systems (Cambridge, Mass.) divided more than $2 million in contract awards to investigate the performance characteristics of an aircraft with reconfigured flight controls after flight control damage or an actuator failure.

Once the concept development phase is completed, the Air Force plans to issue contracts for hardware and software, including the systems capability assessment module and the reconfiguration computer, by late 1986. Several prototype systems will be installed and evaluated on test aircraft in 1987. By 1989 the control surface reconfiguration will be demonstrated in flight on a modern high-performance jet—probably the Advanced Fighter Technology Integration (AFTI) F-16, which is generally used as a testbed for developmental systems.

Wright-Patterson's Aeronautical Systems Divison has received $13.1 million for the initial concept development phase of this program. The Air Force had requested an additional $18.9 million for fiscal 1985 and $22.8 million for fiscal 1986. But Congress approved only $4 million for fiscal 1985. Despite the cut, officials are confident that this research will continue to find support in Congress. Says James J. Mattice, deputy director of the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratory in Dayton, Ohio, "This advanced technology not only works to protect the military's investment in expensive combat aircraft but could also have a significant effect on the economics and safety of future civilian aircraft." □

Jeff Richmond, of Danbury, Conn., is a freelance writer who specializes in aerospace topics. He has been an Air Force and commuter airline pilot and a teacher of aeronautics at the college level.



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PERSPECTIVES

Voice mail patent raises cries of protest

In February 1983, Gordon H. Matthews, founder and chairman of VMX (Richardson, Tex.), was awarded U.S. Patent No. 4,371,752 for a computerized voice messaging system, and the voice store-and-forward industry hasn't been the same since. Over the past 2½ years, attorneys for Matthews's company have been contacting other manufacturers of voice mail systems, mainly start-ups, pointing out that VMX has already settled three patent infringement cases out of court—including one with office automation giant Wang Laboratories (Lowell, Mass.)—and is collecting license fees from seven other vendors as well.

For other manufacturers of voice mail systems—which convert analog telephone signals into digital pulses, store them on magnetic disks, and reconvert the voice messages for playback to the intended recipients—the inference is obvious: Pay VMX its due or wind up in court. Specifically, VMX requests that firms pay a $250,000 license plus royalty payments of 6% of the net revenues received from the use, sale, or lease of voice messaging systems covered by the claims of the patent. And the company makes it clear to voice mail vendors that they have little time to waste. "VMX is currently evaluating its licensing position," the company wrote competitor Brooktrout Technology (Wellesley Hills, Mass.) in a letter dated February 27, 1985, "and it cannot be guaranteed that the current offer will be available for any more than a limited time."

John H. Knowles, Jr., Brooktrout's VP of marketing, insists that VMX's patent is of questionable validity. "We use a completely different technological approach to voice store-and-forward than they do, but their patent covers the entire concept of forwarding speech, not the particulars. It's a little like McDonalds having a patent on a drive-in window at a hamburger stand." A U.S. Patent Office spokesperson, however, says that all applications are carefully scrutinized by a specialist in the field. Those that are deemed too broad, he says, are rejected or returned for modification.



Gordon H. Matthews, VMX's founder and chairman, helped establish the voice messaging marketplace.

Knowles also claims that VMX, which posted $22.8 million in sales in the first nine months ended in March, is singling out smaller companies like his, which just completed $1 million in financing, while shying away from more powerful voice mail vendors like IBM and AT&T. "VMX can afford to stay in court for the next 10 years," he says, "while a company like ours can afford to stay in court for about 10 days."

Nevertheless, some small companies are challenging VMX. After being charged in a copyright infringement lawsuit by VMX in 1983, Voicetek (Newton, Mass.) filed a counterclaim in Boston's U.S. District Court, charging that VMX was trying to monopolize the market by crowding out start-ups and that its patent was invalid because other companies, such as IBM, had already published information about similar systems prior to the VMX patent. "One cannot pioneer that which has already been invented," argued Voicetek's attorneys. The suit was later settled out of court.

Other small firms have similar interpretations of VMX's patent rights, but most have opted to settle rather than fight. VMX's patent seems too broad to be valid, "and you'd like to attack it," says the attorney for one vendor, both of whom asked not to be identified. But with "so much at stake," he says, his client eventually worked out a licensing deal with VMX.

In each out-of-court settlement, the exact terms of the licensing arrangements were kept confidential as part of the agreement. "That should give you a clue," says another attorney who requested anonymity, "that those licenses have been fairly cheap"—a lot less than the fees that VMX requests publicly, he suggests.

But even if the out-of-court settlements aren't particularly lucrative for VMX, many believe that the company still benefits from actively defending its patent. "It's like an army going through a forest and cutting down trees behind it to slow down an army that's pursuing," says Jeff Swartz, editor of *Invention Management*, a patent newsletter published in Brookline, Mass. "Apparently, VMX is gaining market share while using the patent to legally slow down the competition."

For its part, VMX offers no apologies for the route it is taking. The patent is valid, says VMX's VP of marketing and sales, Jim Hawkins, and was issued only after an extensive special audit review by the U.S. Patent Office. "This is not something they stumbled into," says Hawkins, and VMX plans to "aggressively defend its patent" against all comers. Hawkins denies that VMX is singling out smaller companies for possible litigation; he cites as an example the company's confidential licensing agreement with Wang.

But another large company might ultimately force major revisions in VMX's assumptions and strategies. In a letter dated December 16, 1984, VMX notified Sperry Corp. (Blue Bell, Pa.) that it considered Sperry in violation of its patent and expected the company to take out a license with VMX. Sperry responded by petitioning the U.S. District Court in Wilmington, Del., for (among other things) "a judgment declaring that each and every claim of United States Letters Patent No. 4,371,752 is invalid." That case is still pending. □

—Al Furst

Lucasfilm computerizes audio editing



Lucasfilm's James A. Moorer at the control panel of the Audio Signal Processor, a digital system for recording, mixing, and editing film and video soundtracks.

In order to speed up the editing of film and video soundtracks, Lucasfilm (San Rafael, Cal.) has developed a general-purpose digital audio system known as the Audio Signal Processor (ASP). To date, ASP has been used for intermediate processing on the films *Indiana Jones and the Temple of Doom* and *Amadeus*. An improved version, to be marketed before the end of 1985 under a different name, will combine the functions of a multitrack tape recorder, a mixing console, a sound editing desk, a multitude of signal processors, and a music and voice synthesizer. In short, it could replace every piece of equipment now used by music-recording and film-sound studios.

ASP will convert all dialogue, music, and sound effects into digital form, and then manipulate them using a high-speed dedicated processor equipped with large amounts of memory. Today the various sound elements are recorded on individual reels of sprocketed magnetic film called "units." A single scene may contain as many as 130 separate units, timed precisely to fit the sequence of images. Thus whenever the film editor makes changes to alter the visual pacing, the sound editors have to recut each unit, and then realign and remix them all. More often than not, by the time the sound editors have finished their work, the film editor has made additional changes.

Editing is not the only problem. Conventional sound recording and processing also have drawbacks. For example, dialogue recorded on a set typically includes background noise that is lacking when voices are recorded in a studio. Thus the various units must be carefully processed to create the illusion that they were all recorded in the same acoustical environment. A further problem is generation noise: In a typical film production, many sound elements go through six generations before they reach the final print, picking up noise and distortion at each step along the way.

Because ASP is fully digital, audio engineers will be able to mix and balance tracks as many times as they want without producing generation noise—they will be dealing, after all, with strings of 0s and 1s instead of easily distorted analog waveforms. Moreover, they will be able to test combinations of sound effects before recording them. Because future software will perform functions now done by numerous pieces of hardware, ASP will be the last major piece of audio equipment a studio will ever have to buy, contends James A. Moorer, head of Lucasfilm's Digital Audio Project. "When ASP is finished," he says, "we want to become a software house."

New technology will allow the basic version of ASP to be sold for about $150,000, a fifth of the price envisioned when the project began in 1983. At the heart of ASP is a 32-bit Motorola 68000 microprocessor, which communicates through a high-speed local-area network with up to eight 24-bit digital signal processors (DSPs). Each DSP is linked to two or more 128-kilobyte memory banks, up to four 350-megabyte hard-disk drives, and analog-to-digital and digital-to-analog converters that translate sound into digitized form and then back into sound.

A magnetic hard disk can store 40 minutes of monaural sound over the full audio spectrum or about seven minutes of sound in the six-track format that is standard on 70-mm film. This capacity is not as limited as it seems, because silent passages do not take up any storage space, and film sound rarely requires the full audio spectrum. By compressing the bandwidth, the amount of a soundtrack stored on each disk can be increased. Nevertheless, the Lucasfilm team is looking into storage systems with greater capacity, including 800-megabyte hard disks and 1.2-gigabyte optical discs, which might be useful for archival sound storage.

The potential of ASP is limited only by the availability of software. One of the first pieces of software to be developed at Lucasfilm was a sound-editing program called EdiSon, which serves as both a sound file editor and a cue-sheet editor. Employing a mouse to manipulate screen icons on a high-resolution graphics terminal, users can recall sounds stored in the machine's memory and edit them. Icons representing individual sounds can then be positioned on the screen according to when they occur and on which track. EdiSon can handle a total of 64 tracks; eight are displayed on the screen at a time, while the others can be viewed by scrolling the information

GABRIEL BALOGH

horizontally across the screen like a spreadsheet.

Lucasfilm has also developed several sound-processing programs. One records a large variety of sound sources—for example, each of the 88 keys of a grand piano—and plays them back in any desired order on up to five tracks. Another program constructs a digital filter consisting of 256 94-hertz bands, which eliminates extraneous noise accompanying dialogue that has been recorded on a film set. Music composing, synthesizing, and printing programs are in various stages of development. In addition, the Lucasfilm team is working on a software-based audio mixing console. The prototype resembles a standard recording studio console, except that the function of each knob and volume-control slider is assigned by the users and identified by an LED alphanumeric display. The next step will be to add a touch-sensitive graphics screen that enables the user to select the various functions.

The Digital Audio Project is but one of several technology development efforts under way at Lucasfilm. Last spring the company released its first piece of commercial hardware: a computerized video editing system called EditDroid, being marketed by Convergence (Irvine, Cal.). By combining EditDroid and ASP, Lucasfilm hopes to speed up video production time dramatically. "The bottom line for a TV studio," Moorer says, "is how fast they can get an episode out the door." □

—Paul D. Lehrman

Silicon polymer: cheaper plastics, denser chips

Polysilanes—polymers with backbones of silicon atoms—may enable manufacturers to lower the cost of making plastic films and tapes, according to recent research reports; they also show promise as highly sensitive imaging layers in photolithography processes for producing ultrahigh-density computer chips and as precursors to tough ceramics.

The first polysilanes, identified in the 1920s, contained methyl and other simple hydrocarbon (alkyl) groups on the silicon atoms, and were mostly insoluble, intractable solids of little commercial utility. But by substituting long-chain alkyl groups, aromatic (benzenelike) groups, or nitrogen-containing groups called amines on the silicon atoms, chemists have recently been able to obtain softer materials that are soluble in many organic solvents.

These soluble polysilanes could serve as photoinitiators (substances that act in conjunction with light to start chemical reactions) in the polymerization processes used to make plastic films and audio and video tapes. Visible light ruptures the bonds in polysilanes, creating highly reactive chemical substances called free radicals, report researchers Robert West and Andrew Wolff of the University of Wisconsin (Madison). The free radicals react with various monomers, causing them to polymerize to such key industrial plastics as polystyrene, polymethyl methacrylate, and polyvinyl chloride. But unlike the photoinitiators used now, which have to be blanketed in an expensive inert gas such as nitrogen, the polysilanes are not oxygen-sensitive. According to West, they can be used in the open air, greatly lowering production costs.

The insensitivity to oxygen is made possible by adding amine groups to polysilane's silicon atoms. This process was developed at 3M (St. Paul, Minn.), which has supported the Wisconsin work. West and his colleagues have found that they can systematically vary the number and type of amines on the silicon chain. This, says West, makes it possible to design a polysilane that fragments in a way tailored to maximize yields of a particular plastic.

Meanwhile, scientists at the IBM Research Laboratory in San Jose, Cal., have found that soluble polysilanes can be extremely useful as light-sensitive layers in the conventional "wet" and the newer "dry" photolithographic processes for making computer chips. In one widely used form of photolithography, light is beamed through a patterned mask onto a light-sensitive layer deposited on a silicon substrate. In the wet process, parts of the exposed layer are dissolved away by solvents to create the circuit features. In dry processes, the exposed portions are removed by gas plasmas.

Polysilanes are ideal for the chip manufacturing processes in which multiple layers are laid down on silicon, says IBM researcher Robert D. Miller. Not only are polymers easily formed into images with light, but the unexposed portions of the polymer are quite resistant to attack by the oxygen plasmas often used in dry processes. The net result, says Miller, is that the plasmas are able to etch "deep patterns with vertical walls," which allow circuit features to be closely spaced. The need for such high resolution will grow in the future as the circuit density of semiconductor chips increases.

Polysilane photoresists may help streamline the photolithography process by eliminating the need for the gas plasmas in forming images on the silicon substrate. Scientists at Sandia National Laboratories (Albuquerque) are experimenting with a form of the polymer somewhat different from that used at IBM. Organic chemist John M. Zeigler and physical chemist Larry A. Harrah have found that ultraviolet light beamed through the patterned mask causes the exposed portions of the polysilane layer to be immediately swept away. Thus no subsequent "development" of the image by the gas plasma is necessary. Such "self-developing" photoresists have long been sought by industry.

Zeigler believes that the first commercial applications of Sandia's photoresist could come within one or two years and will probably be used at first to make fairly simple integrated circuits. Later, however, he foresees its use in making VLSI (very-large-scale integration) chips with more than a million transistors apiece.

Polysilanes are also receiving attention as precursors to ceramics, particularly silicon carbide, a very tough material used in rocket nozzles, turbine blades, and radar domes. Researchers in the U.S. and Japan have found that polysilanes decompose when heated to around 1000° C, forming silicon carbide. Industry is interested in this technique because it offers a route to purer and more crack-resistant ceramic coatings. □ *—Gordon Graff*



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RESOURCES

Following are sources for further information about topics covered in the feature articles in this issue.

Parallel processing, p. 20

"Perspectives on supercomputing." B. L. Buzbee & D. H. Sharp. *Science*, Feb. 8, 1985. Includes an evaluation of the impact parallel architectures may have in boosting performance.

"Reinventing the computer." Tom Alexander. *Fortune*, March 5, 1984. An overview of the supercomputer market, with a good explanation of the need for parallelism.

"NSA seeks super parallel processors." Karen Berney. *Electronics Week*, Dec. 17, 1984. Describes the National Security Agency's plans to build a $12 million research center for developing massively parallel computers.

"Supercomputers: a strategic imperative?" Dwight B. Davis. *High Technology*, May 1984. Covers the plans of the traditional supercomputer vendors, including their ambivalence toward parallelism.

"Advanced parallel architectures get attention as way to faster computing." Tom Manuel. *Electronics*, June 16, 1983. Dated, but provides good explanations of several still-current approaches to parallelism.

Cold war in the ocean depths, p. 29

"Sound searching the murky seas." David Ritchie. *High Technology*, March 1983. Review of sonar surveillance technology.

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Technology transfer officials

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TECHSTARTS

DNA Plant Technology:
CLONING TASTIER TOMATOES

The quest for a tomato that tastes vine-ripened when picked green enough to ship cross country is part of a contract between agricultural biotechnology firm DNA Plant Technology (DNAP) and Campbell Soup, which previously underwrote DNAP's "extra meaty" tomato for processed foods. These projects rely on cloning (which generates plants faster than traditional methods can) to shorten the time it takes to breed new varieties. Others use protoplast fusion (which combines cell contents from different plant species) to create new hybrids.

In addition to doing research under contract (other clients include Hershey Foods, General Foods, and Brown and Williamson Tobacco), DNAP has formed two joint ventures. The first, with Koppers Co., will develop and sell kits to diagnose plant disease—including a low-priced kit for spotting the most common grass diseases. The second, with Swiss company Firmenich, aims to synthesize large quantities of flavor- and fragrance-producing chemicals from plants by culturing only the chemically active cells rather than growing whole plants.



DNAP's Richard Laster wants to tailor crops to industry's needs.

Financing: $10.5 million in venture capital, with Kopvenco (a subsidiary of Koppers) and Campbell Soup the principal investors. Another $12.8 million from a January 1984 public offering of 2.53 million shares sold at $5.75 each. The OTC stock symbol is DNAP.

Management: President and CEO Richard Laster was formerly president of Maxwell House and executive VP of General Foods. Executive VP and scientific director William Sharp was previously a research director at Campbell Soup's Institute for Research and Technology. VP and associate director of research David Evans was also at the Campbell research institute, as manager of cellular genetics.

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Telenova:
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As more electronic devices get adapted to the office, many businesses are choking in a tangle of equipment and electrical cable. Telenova's solution, commercially available since March, links digital telephones and desktop computers in a network that can operate over standard telephone wires. The system's controller allocates the use of devices such as printers and modems to personal computers connected to special phones that handle voice and data simultaneously. The system is targeted at small businesses (10–100 employees), whereas similar systems—from Northern Telecom and the IBM subsidiary Rolm among others—are for medium-sized and large businesses.

Financing: $20 million in venture capital financing from investors including Rothschild, Allstate Insurance, First Interstate Capital, Cherry Tree Ventures, McMicking & Co., John Hancock Venture Fund, U.S. Venture Partners, Concord Partners, and Michigan Capital and Service.

Management: Company founders are former executives of digital telecommunications equipment maker Vidar, owned by Cleveland-based TRW. Chairman and CEO Edmund Keane was Vidar's president, VP of engineering Tracy Storer was manager of the digital switching line, and VP of manufacturing Carl Lauritsen was a plant manager. President and COO M. Peter Thomas was president of ITT's Telecom Network Systems division and was previously VP and general manager of General Instrument's Business Systems division.

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Mosaic Systems:
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Ever since the microchip came along to replace bulky, expensive circuit boards, computer makers have dreamt of squeezing all of a machine's circuits onto a single piece of silicon. Such a complex integrated circuit would cover much of a silicon wafer (which normally holds dozens of chips that are sawed apart when fabrication is complete). But attempts to produce wafer-scale integrated circuits have so far failed; the most publicized effort was abandoned last year by Trilogy. In April, Mosaic Systems produced a "computer on a wafer" by gluing individual chips onto a wafer that contains a grid of chemically deposited interconnections. Although not true wafer-scale integration, the design eliminates bulky wires and associated components. Mosaic is shipping wafers to flight simulator maker Evans & Sutherland and electronics manufacturer Siemens for evaluation.

Financing: $8 million in venture capital from investors including Advanced Technology Ventures, Venrock Associates, Evans & Sutherland, and Hambrecht & Quist.

Management: President Robert Johnson was VP of engineering for Burroughs, where he organized the research group that developed an earlier version of the interconnection wafer. VP of engineering and technology Herbert Stopper headed advanced technology groups at General Electric, AEG-Telefunken, and Burroughs. VP of architecture Cornelius Perkins previously led engineering projects for Burroughs.

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COMMERCIALIZING THE MAGIC BULLET

Monoclonal antibody firms expand market for diagnostic kits

A decade after they were first created, monoclonal antibodies have yet to live up to early marketplace expectations. Still, sales of monoclonal-based products reached $50 million last year and are projected to exceed $2.5 billion by 1990.

Antibodies are proteins made by the body's white blood cells in response to specific foreign invaders (antigens). But they can also be created in the laboratory by cells called hybridomas—dedicated factories, each of which produces large amounts of only one type of antibody (which in turn binds to only one type of antigen). This specificity and productivity of monoclonal antibodies, coupled with their great variety, has inspired a host of new product ideas in diagnostics and therapeutics for human and animal healthcare.

The vast majority of available products are *in vitro* (outside the body) diagnostic kits. Broad product use is still limited by the difficulty and expense of manufacturing antibodies in commercial quantities and the need for product approval by the Food and Drug Administration. But clinical trials are proceeding swiftly in all areas of application.

The $500 million market for immunodiagnostics consists largely of nonspecific, antibody-based *in vitro* tests—such as therapeutic drug monitoring, pregnancy tests, and tests for other blood and urine proteins—that will eventually be replaced by monoclonal antibodies. Their greatest potential, however, is in expanding the market with new tests. This arena includes microbiology determinations, early and highly specific cancer testing, and the monitoring of components of the immune system for AIDS patients.

by Nina M. Siegler and Michael H. Graham

Monoclonal antibodies will also create new markets for *in vivo* (inside the body) imaging of internal organs and tumors by means of radioactive tagging. All told, by 1988, monoclonal antibody tests could account for over $1 billion of the projected $4 billion diagnostic products market.

Established firms such as Abbott, Becton Dickinson, Johnson & Johnson, and Syntex are joining the monoclonal marketplace, along with several smaller firms that are worth investor interest. Among these companies are Centocor (Malvern, Pa.), Genetic Systems (Seattle), and Hybritech (La Jolla, Cal.). The investor is cautioned that stocks from companies involved exclusively in biotechnology are highly volatile, being more sensitive to stock market expectations than any other high technology group. Moreover, with substantial revenues still far into the future, there are minimal earnings to support valuations.

Centocor (OTC: CNTO) is developing monoclonal antibody-based diagnostic blood tests, imaging products, and human therapeutics, especially for specific cancers and infectious diseases. The firm has successfully brought to market four diagnostic tests, and another nine products are now in clinical evaluation, including a blood test for AIDS. Centocor has product research agreements with major corporations such as FMC and Hoffman LaRoche, and collaborates with such research institutions as Massachusetts General Hospital and the Dana Farber Cancer Institute. To gain immediate access to target markets and to avoid the expense of developing its own sales force, Centocor has formed marketing ties with such companies as Abbott, Toray Industries (Japan), and Warner Lambert.

In 1984, Centocor became one of the first biotechnology companies to show a profit, posting revenues of $12.8 million, which yielded a net income of $703,000 and earnings of 10¢ per share. In 1983, revenues were $7.4 million, and there was a net loss of $835,000 and a loss per share of 12¢. Product sales in 1983 were $1.2 million, rising to $3.2 million in 1984. The difference between such sales and total revenues consists of earnings from contract research and interest income.

Genetic Systems (OTC: GENS) has focused its development efforts on monoclonal-based diagnostic and therapeutic products for infectious diseases. Its first line of tests for sexually transmitted diseases, such as herpes viruses, is now being marketed as Microtrak by Syva, a division of Syntex. The FDA recently approved a Legionnaire's disease test, the first in a line of respiratory disease diagnostics. The company has also developed a therapeutic product that confers protection in animals against an often lethal group of bacteria called *Pseudomonas;* the Cutter Group of Miles Laboratories will conduct the human clinical trials. In addition, Genetic Systems has entered a joint venture with Syntex and Bristol Myers—called Oncogen—to develop cancer-related products.

Genetic Systems has yet to break even, having plowed revenues from contract research and interest income into R&D, product development, and clinical trials. The firm ended 1984 with revenues of $9 million, a $3.9 million loss, and a loss of 20¢ per share; 1983 revenues were $6.5 million, with a loss of $1.5 million and a loss per share of 8¢.

Hybritech (OTC: HYBR) is one of the few biotechnology companies to have its own sales force, targeting its proprietary Tandem line of *in vitro* diagnostic test kits and instruments to the clinical laboratory market. Its products test for the blood and urine protein levels that indicate pregnancy, thyroid disorders, and certain cancers. The firm has expanded into the physicians' office market through a relationship with Richardson-Vicks. Hybritech has several tumor-imaging products in advanced stages of testing and has several cancer-therapeutic antibodies in clinical trials.

The firm reported earnings of 10¢ per share in 1984 but a loss of 5¢ per share the previous year. Product sales were $14.6 million based on revenues of $30.8 million in 1984, up from $6.9 million in product sales and $12.6 million revenues in 1983. □

Nina M. Siegler and Michael H. Graham are principals of Capital Management Services (Baltimore), which specializes in biotechnology consulting and individual investment advisory services.

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